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Memo

DATE: *August 27, 2004*

TO: RHIC E-Coolers

FROM: *Ady Hershcovitch*

SUBJECT: **Minutes of the August 27, 2004 Meeting**

Present: Ilan Ben-Zvi, Andrew Burrill, Rama Calaga, Peter Cameron, Alexei Fedotov, Wolfram Fischer, Ady Hershcovitch, Animesh Jain, Dmitry Kayran, Derek Lowenstein, William Mackay, Nikolay Malitsky, Stephen Peggs, Thomas Roser, Dejan Trbojevic, Dejan Trbojevic, Grigory Trubnikov (Dubna, Russia), Jie Wei.

Topics discussed: Computations and Simulations

Computations and Simulations: talks on intra-beam scattering (IBS) simulations with comparison to RHIC data were given at the meeting by Jie Wei and Alexei Fedotov. Both presentations can be found below.

Jie described latest results of IBS simulation and comparison to experimental measurements in RHIC. Generally, the latest simulation results are in good qualitative agreement with measurements of the stored beams, though some detailed quantitative work remains to be done. More work is needed for injected beams. Experimental results were obtained in a March 16, 2004 run with 100 GeV/u gold beam without collisions. IBS effects were separated from other loss and growth effects. Obtained results: transverse emittance growth and coupling was in agreement within a factor of 2. Dispersion longitudinal growth leads to horizontal growth, which is shared vertically when RHIC operates near coupling. Very good agreement exists among the Fokker-Planck solver, RMS growth formulae, and measurements of longitudinal growth. Bunch Beam Fokker-Planck (BBFP) simulation of beam profiles also show reasonable good agreement with measurements.

Alexei described various BETACOOL simulations, in which different IBS models and formulae were incorporated. The task was to simulate and account for observed emittance growth of 20 – 30% and an 85% in bunch length growth that occurs in one hour. In general Martini/ Bjorken-Mtingwa models give smaller emittance growth by about 30-40% compared to Wei models when realistic RHIC lattice is used and IBS is calculated at each element**.** Both models give correct bunch length growth. However, Martini/ Bjorken-Mtingwa models give an emittance growth of only 9%, while Wei's gives 13%. But, if FODO lattice with higher average dispersion is used Wei's model give an emittance growth of 20%, while Martini/ Bjorken-Mtingwa models give 15% with 86% bunch length growth for all models.

Status report on

IBS beam evolution study & analysis (and Predictions for the 2005 run)

J. Wei, A. Fedotov, W. Fischer, N. Malitsky et al

BNL

J. Qiang

LBNL

August 27, 2004

IBS observables

- rms beam size (bunch length, transverse emittances)
  - Many early studies performed
  - Need to single out IBS from other processes
  - (beam-beam, tune kicker, Landau cavity, dual RF, RF noise …)
- Beam loss
  - Amount of debunched beam (escaping RF bucket)
  - Amount of DCCT loss
- Beam profiles
  - Hollow bunch profile evolution
  - Asymptotic distribution

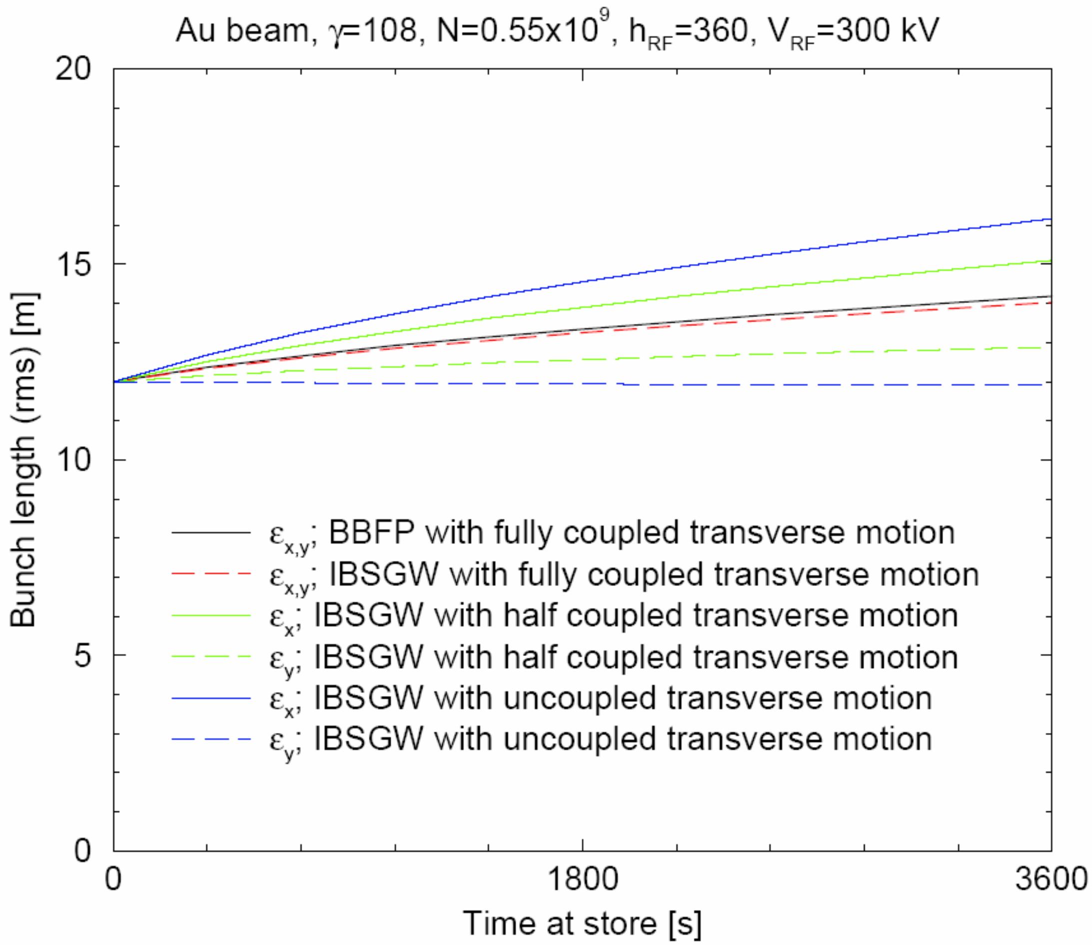
Puzzles and clues

- A. Fedotov reported a large underestimation of transverse emittance growth (~ x4)
  - A factor of 2 was resolved by codes & lattice verification
  - The other factor of 2 is under investigation (to be reported by AF); straight section contribution & approximation
- Measured bunch length can be much larger than those from Fokker-Planck solver
  - Malitsky's re-bucketing simulation gave an answer
  - Estimation using measured rms bunch size underestimates IBS growth!
  - Difference between 1D and 2D rms bunch length (reported by AF)
- Strange Fokker-Planck behavior at injection
  - Under investigation – work to be done

→ Results at store is promising!

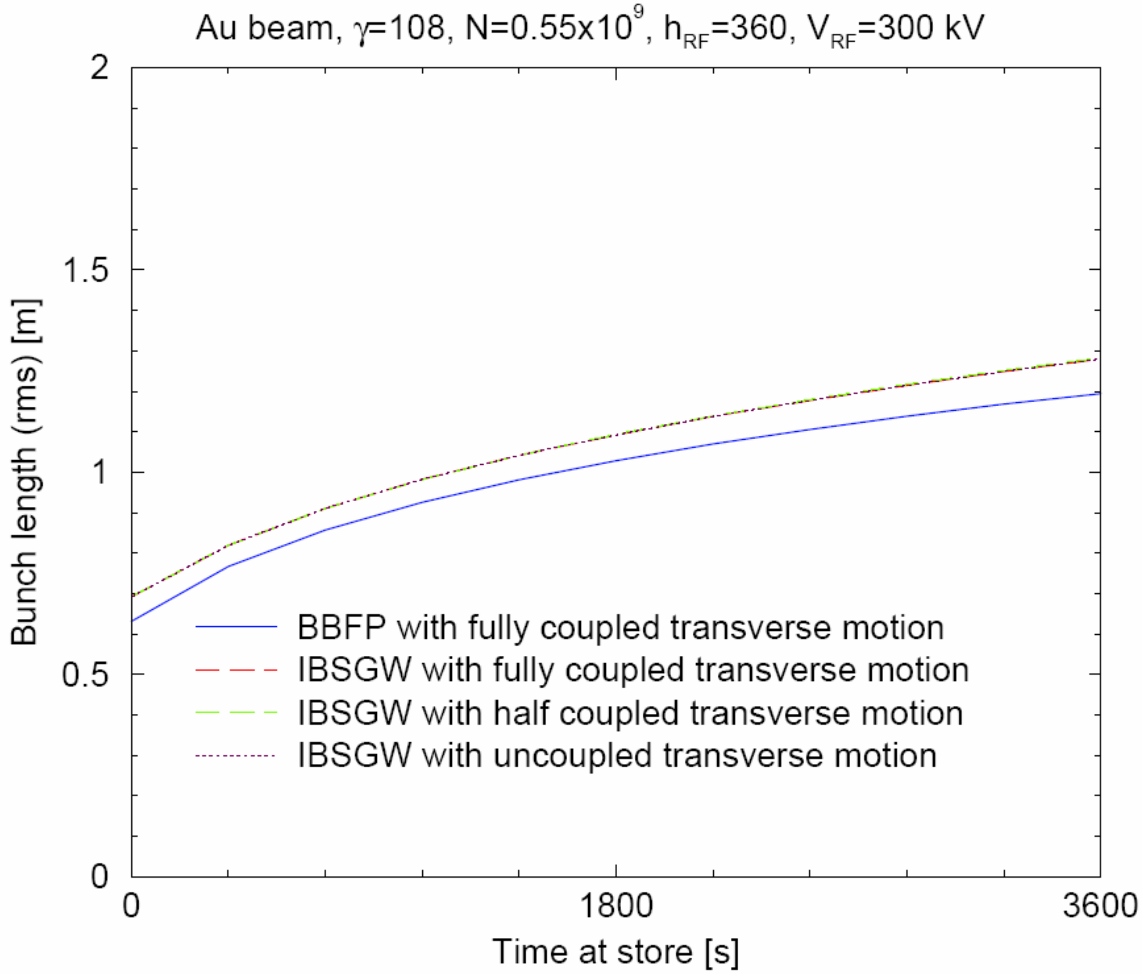
Transverse emittance growth & coupling

- The agreement with measurement is within a factor of 2
- Detailed analysis by AF; further study by G. Parzen
- Coupling mechanism can further contribute



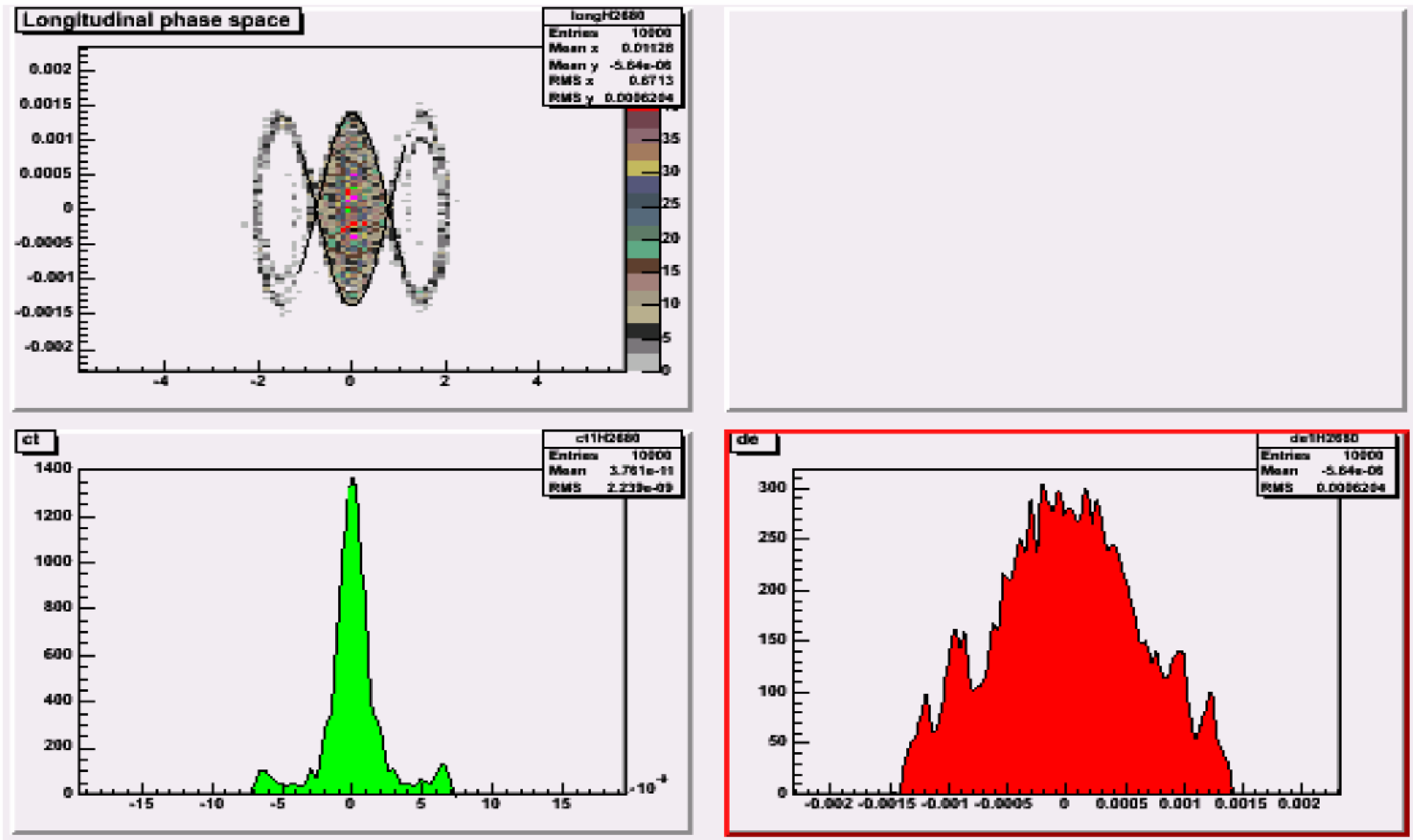
Longitudinal growth

- Very good agreement between Fokker-Planck solver, rms growth formulae, and measurements



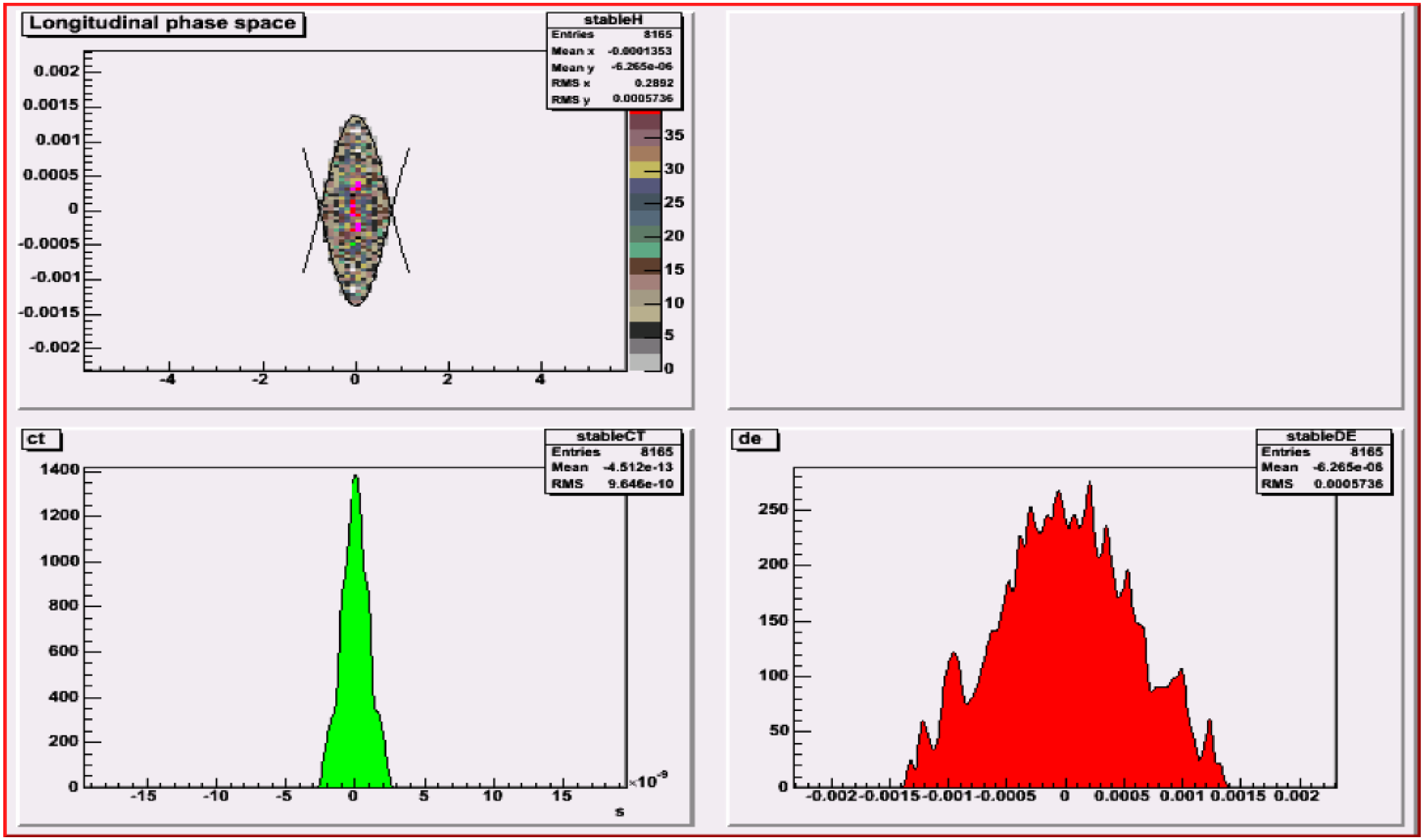
Re-bucketing with a full beam

- Large rms bunch length (2ns) due to satellite beams



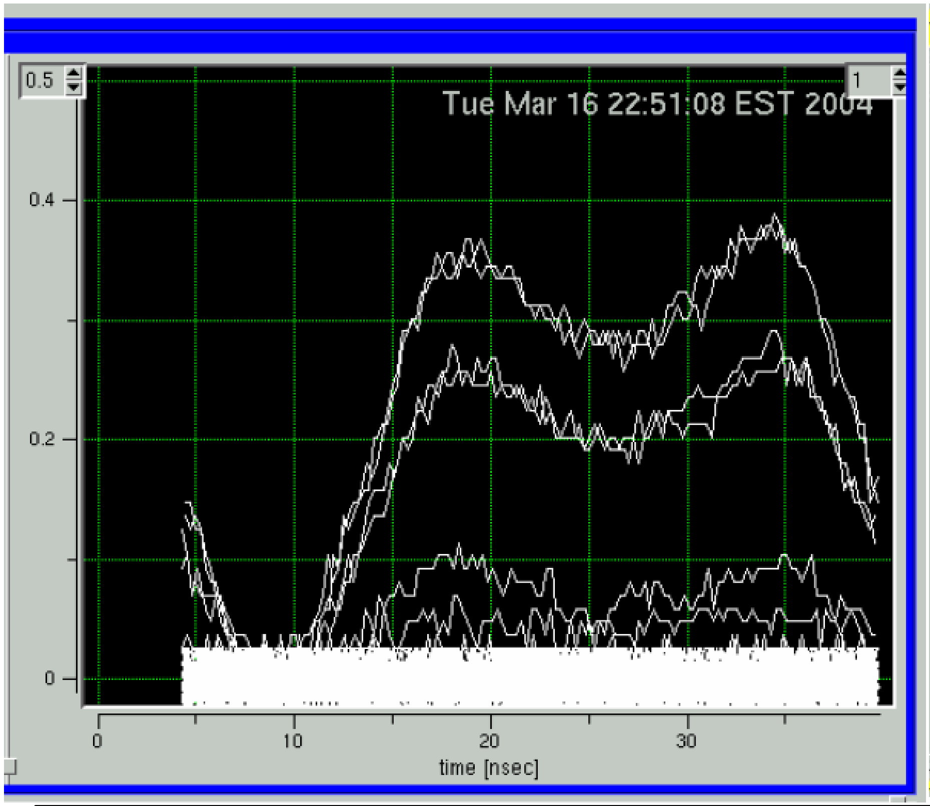
Re-bucketing with a full beam

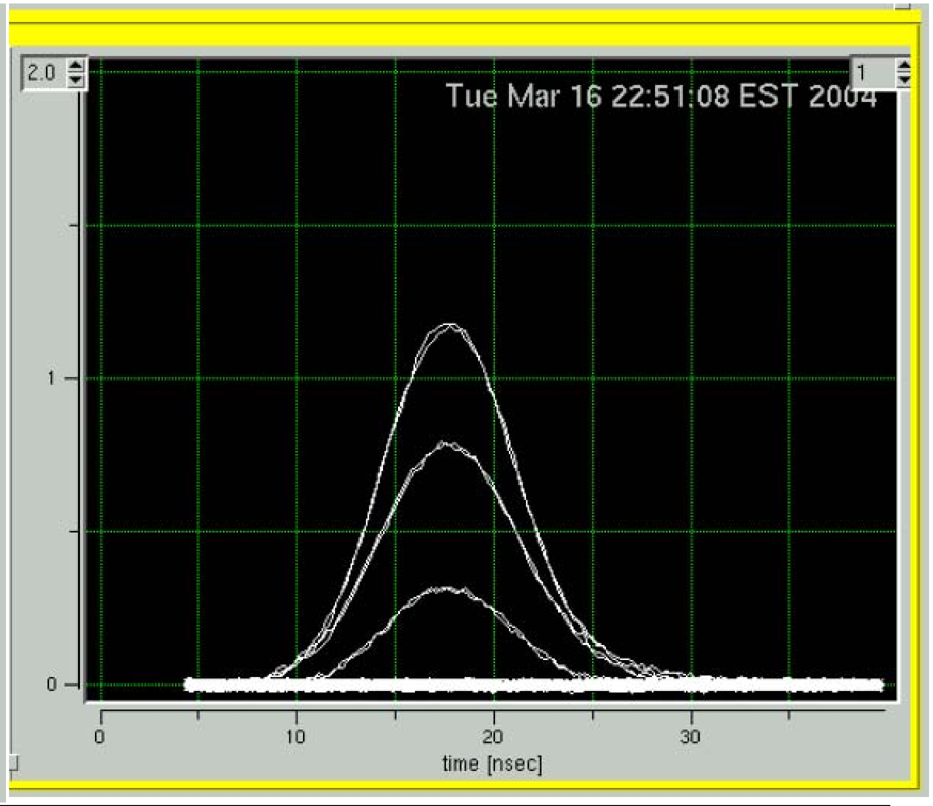
- Maximum rms bunch length is < 1 ns (bucket width > 5 σ)



Beam loss observation (March 16, 2004)

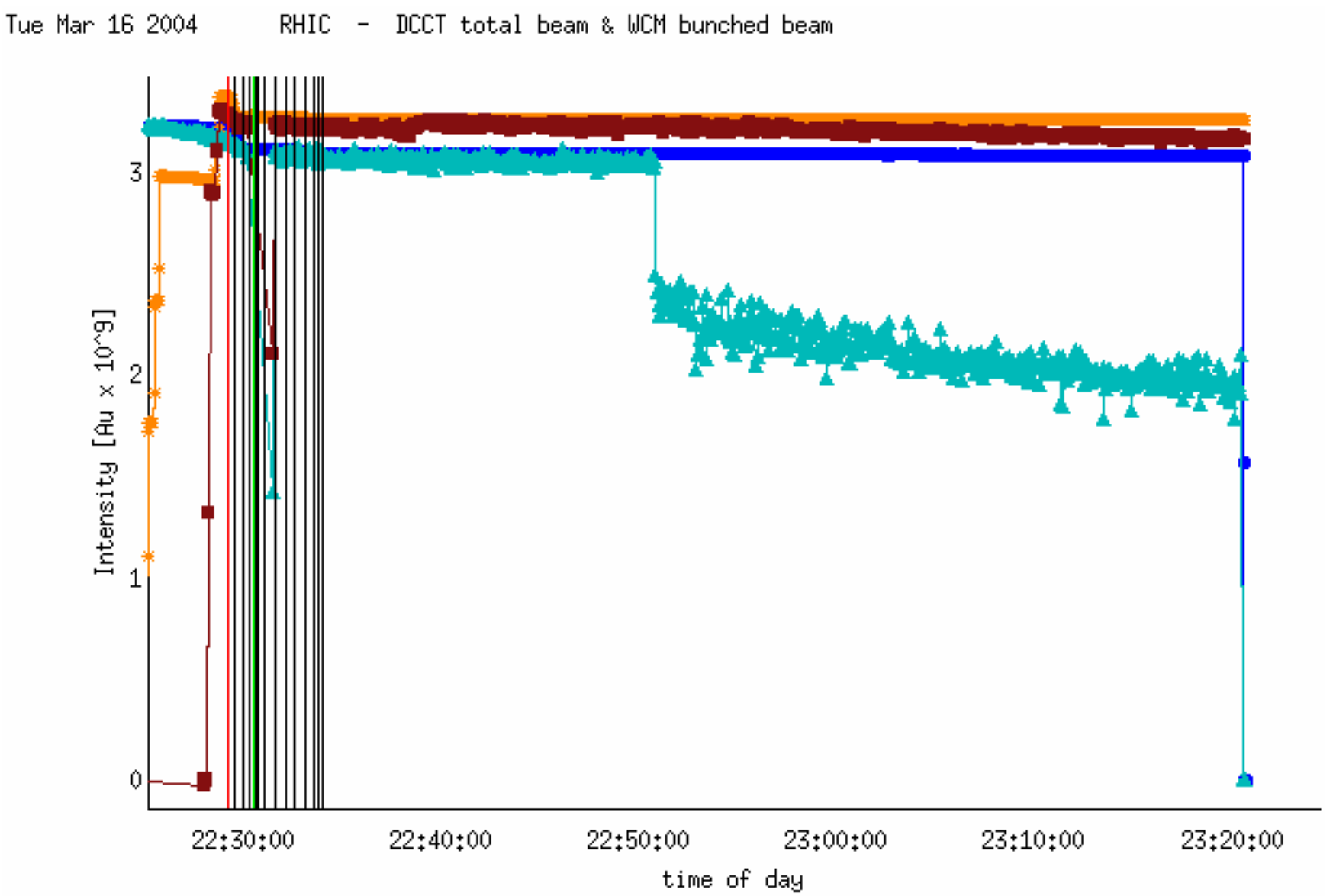
- Gold beam, store at 100 GeV/u with h=360 RF system; no beam collision
- No Landau cavity, no dampers, no kickers
- Hallow beam in blue, normal beam in yellow





Wall current monitor intensity reading

- Distinctively different beam loss (de-bunching) behavior



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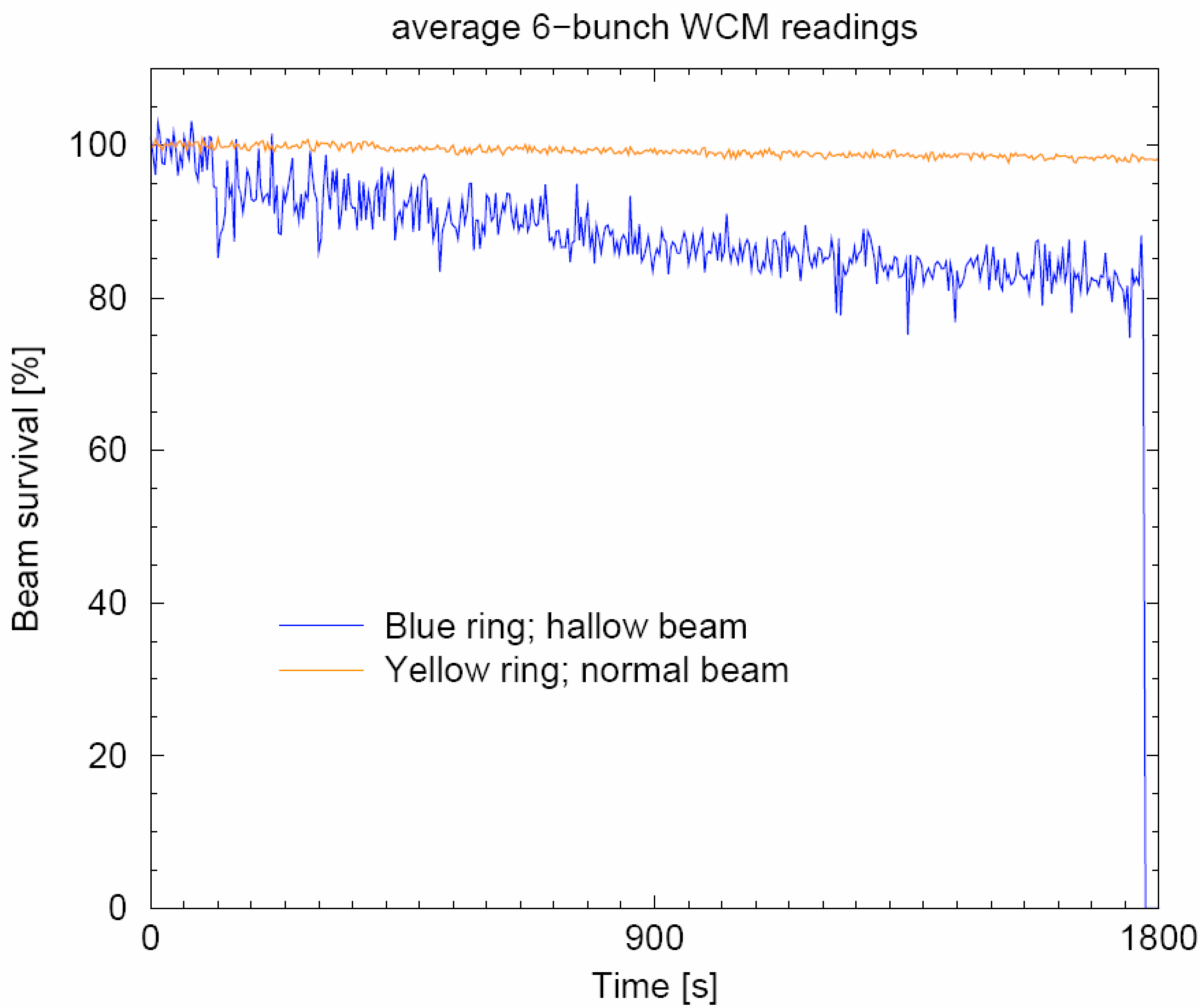
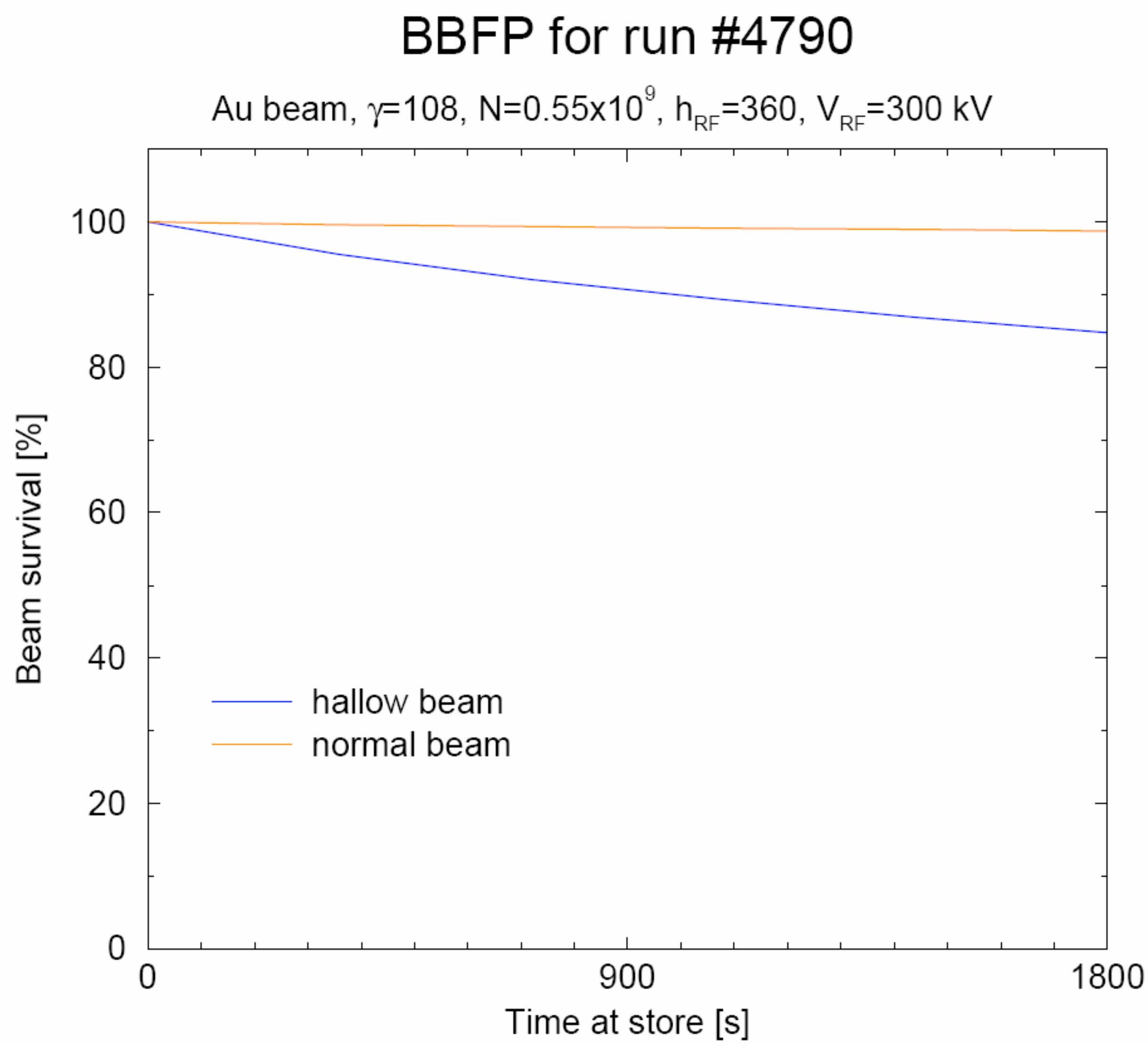
Processed data (Run #4790)

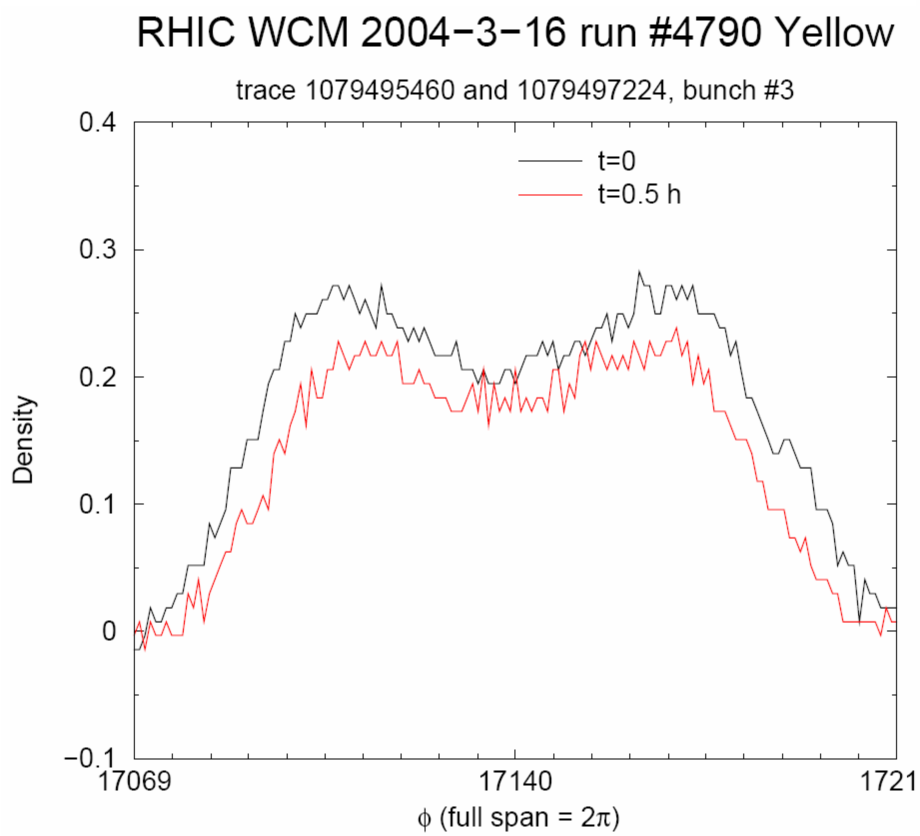


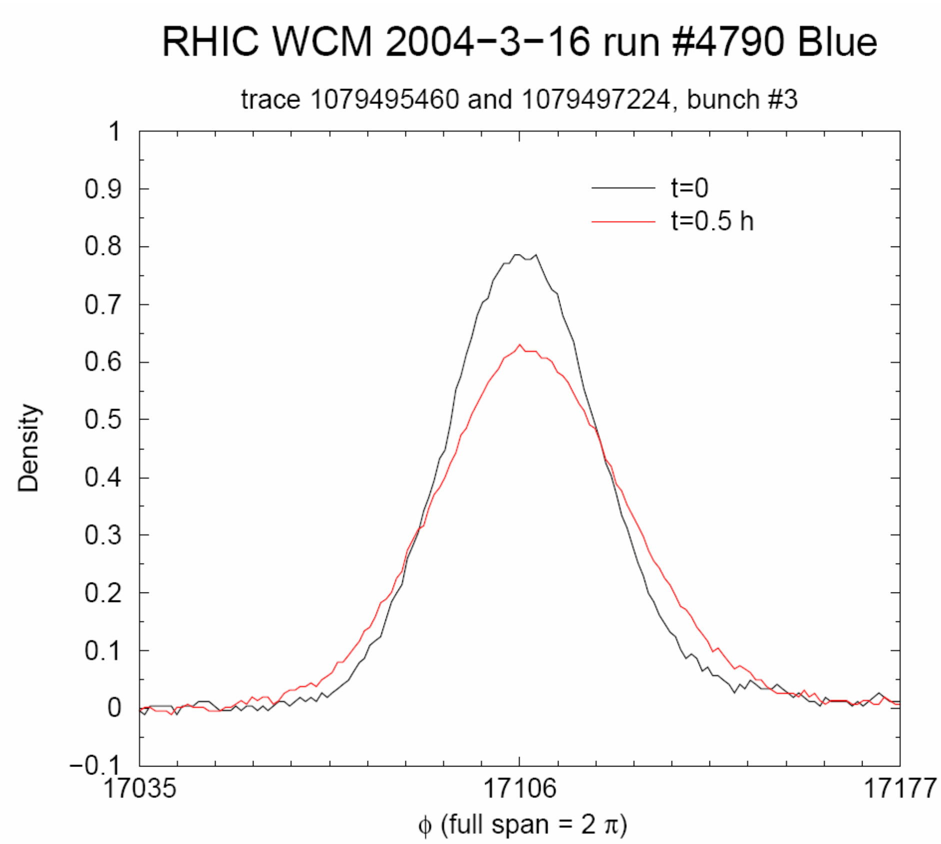
Fokker-Planck simulator BBFP



Processed WCM data

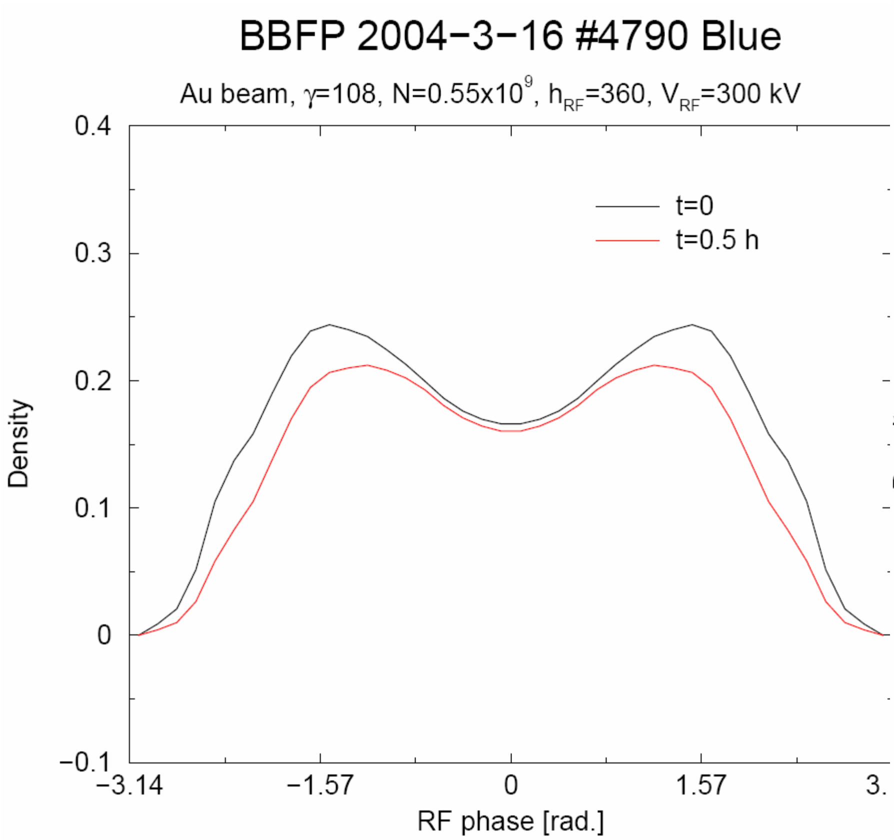
- Normal beam: Gaussian-like shape
- Hallow beam: reducing depth of the hole -> approaching Gaussian

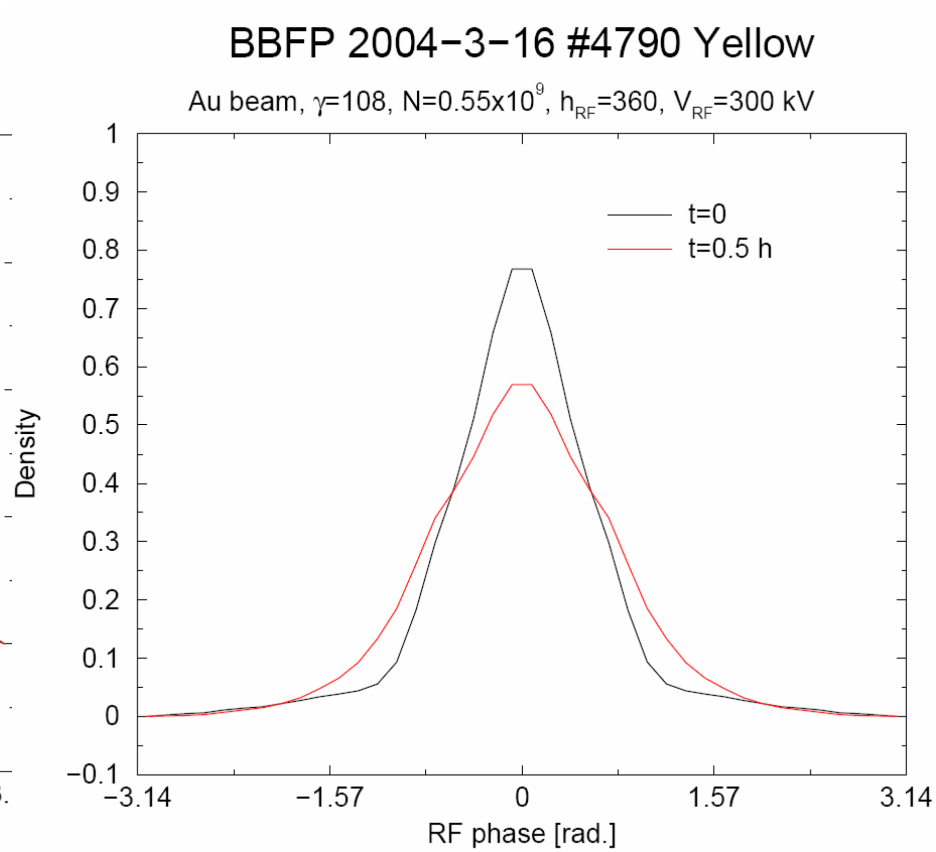




BBFP simulation of the beam profiles

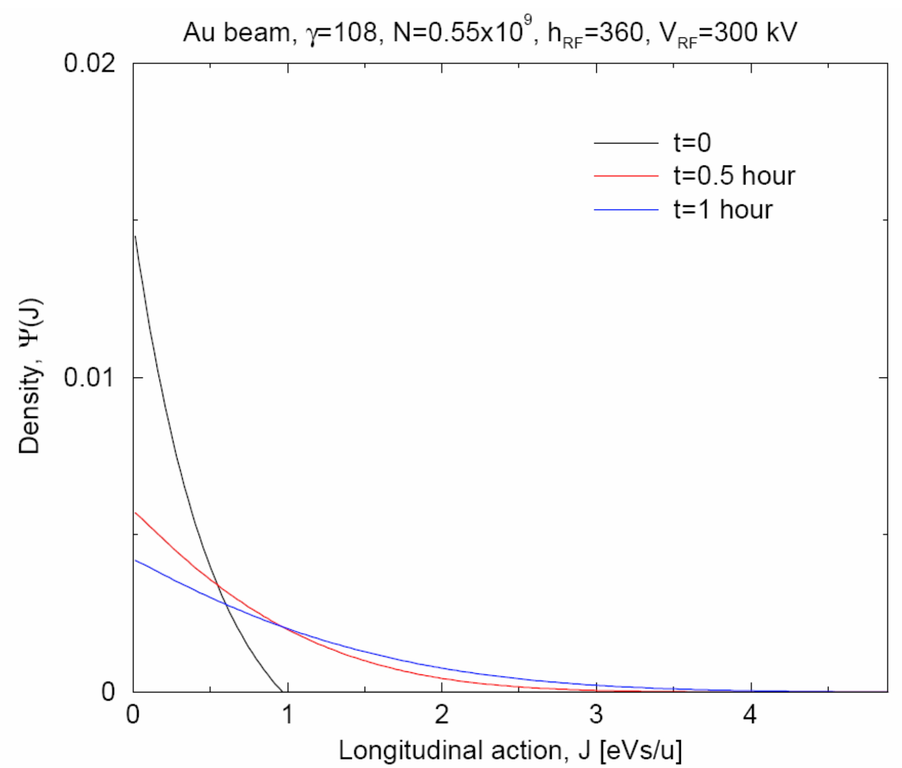
- Good agreement
- Details to be refined

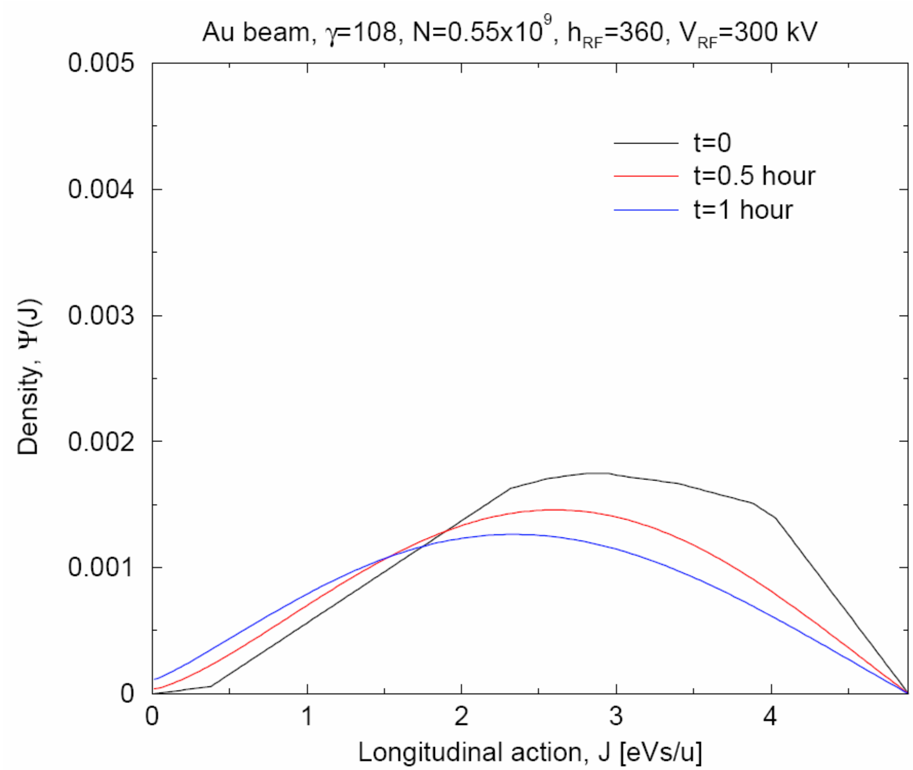




BBFP simulation of beam evolution

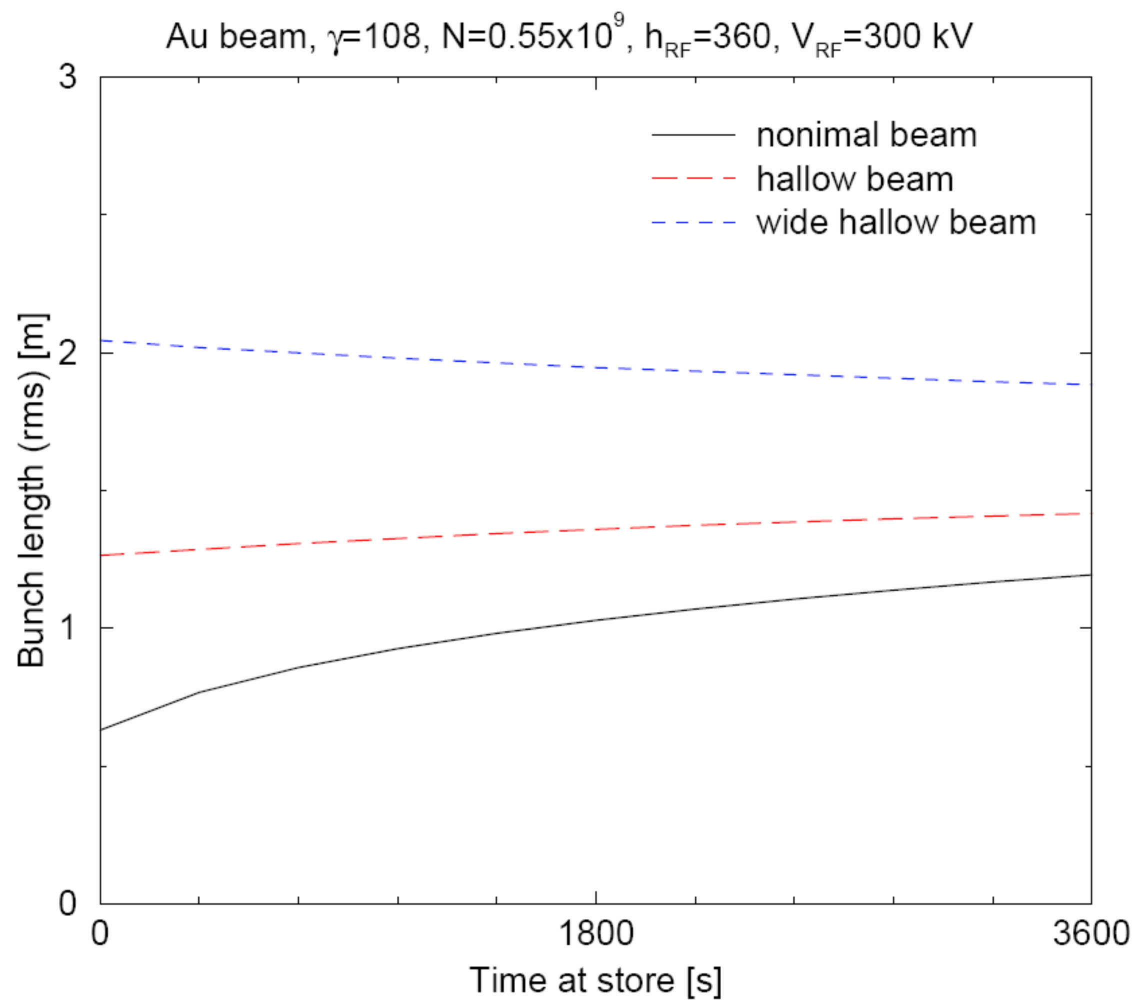
- Density projection in longitudinal action
- Normal and hallow beams





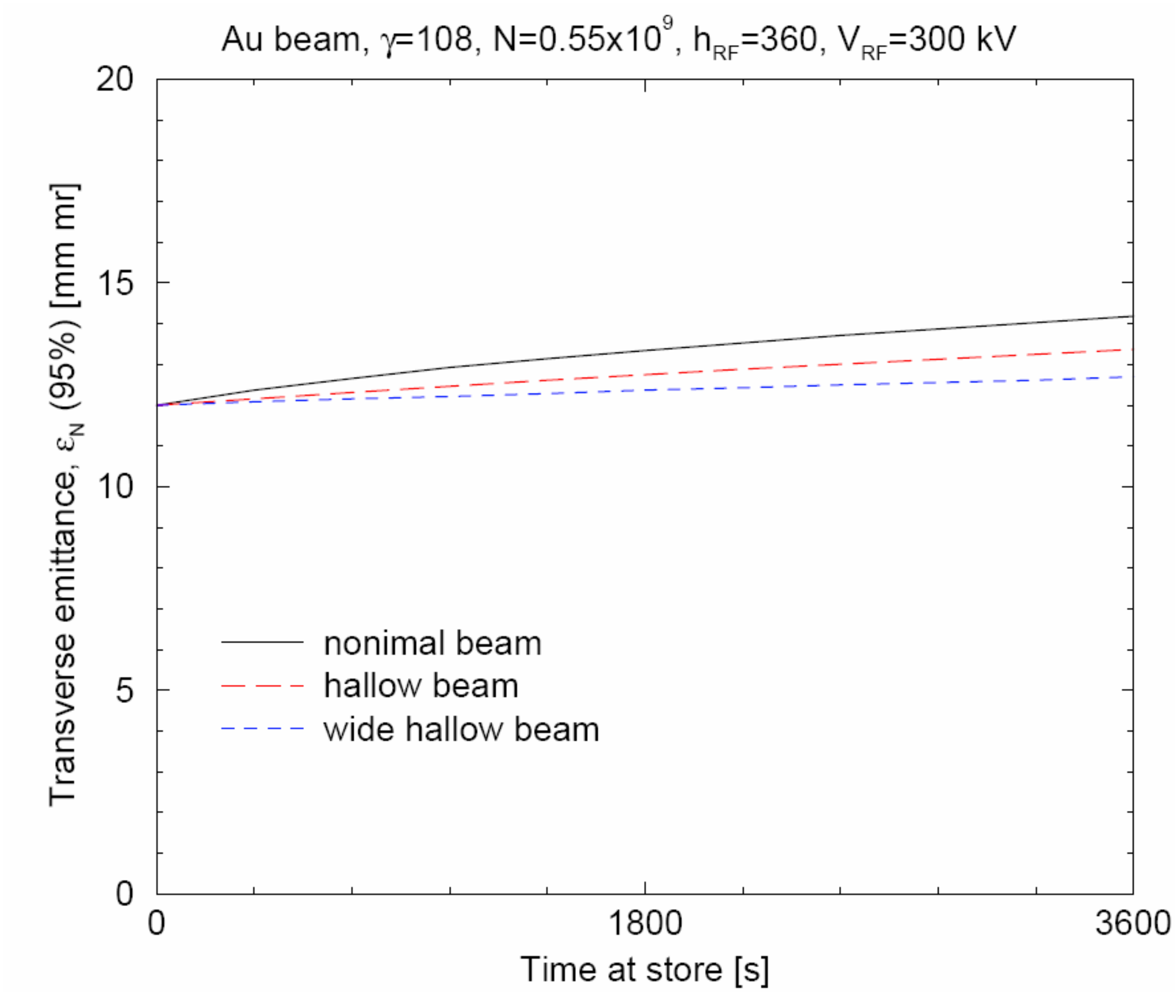
Bunch length

- Agreeable with measurements



Transverse emittance

- Agreeable with measurements



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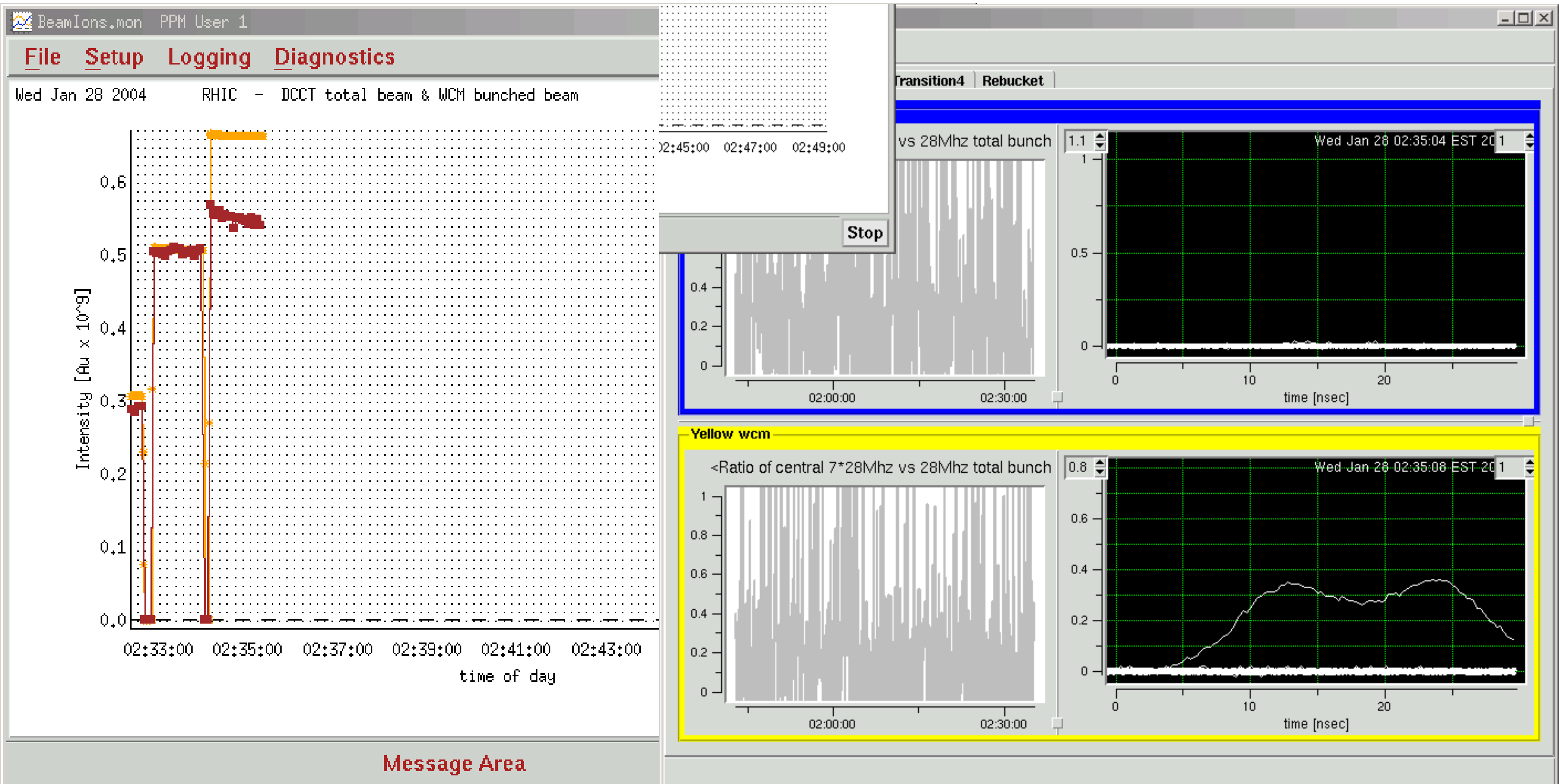
Hollow-bunch study at injection?



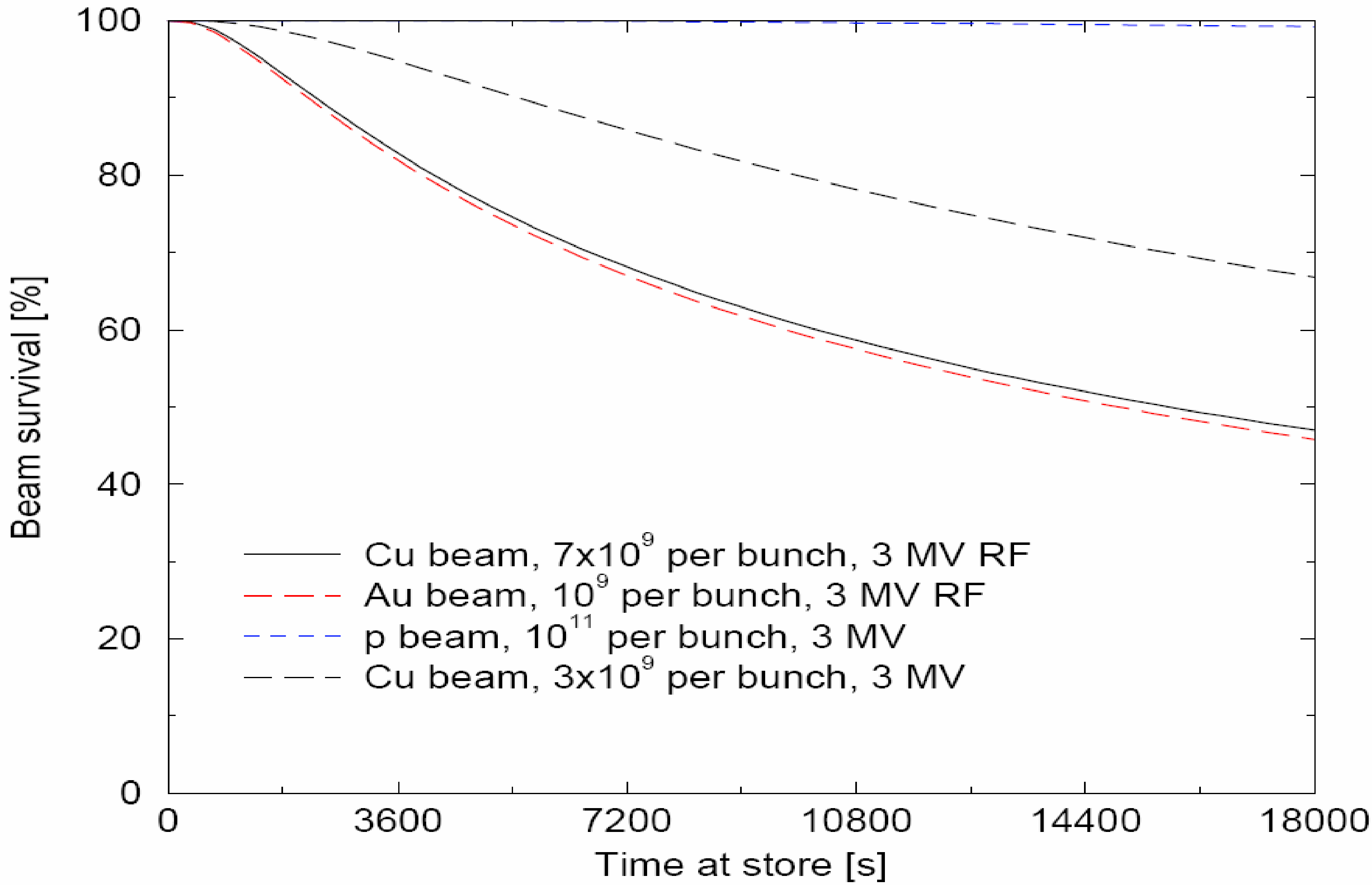
Preliminary summary

- Store:
  - Good qualitative agreement
  - Detailed, quantitative work to be done
- Injection:
  - Work to be done

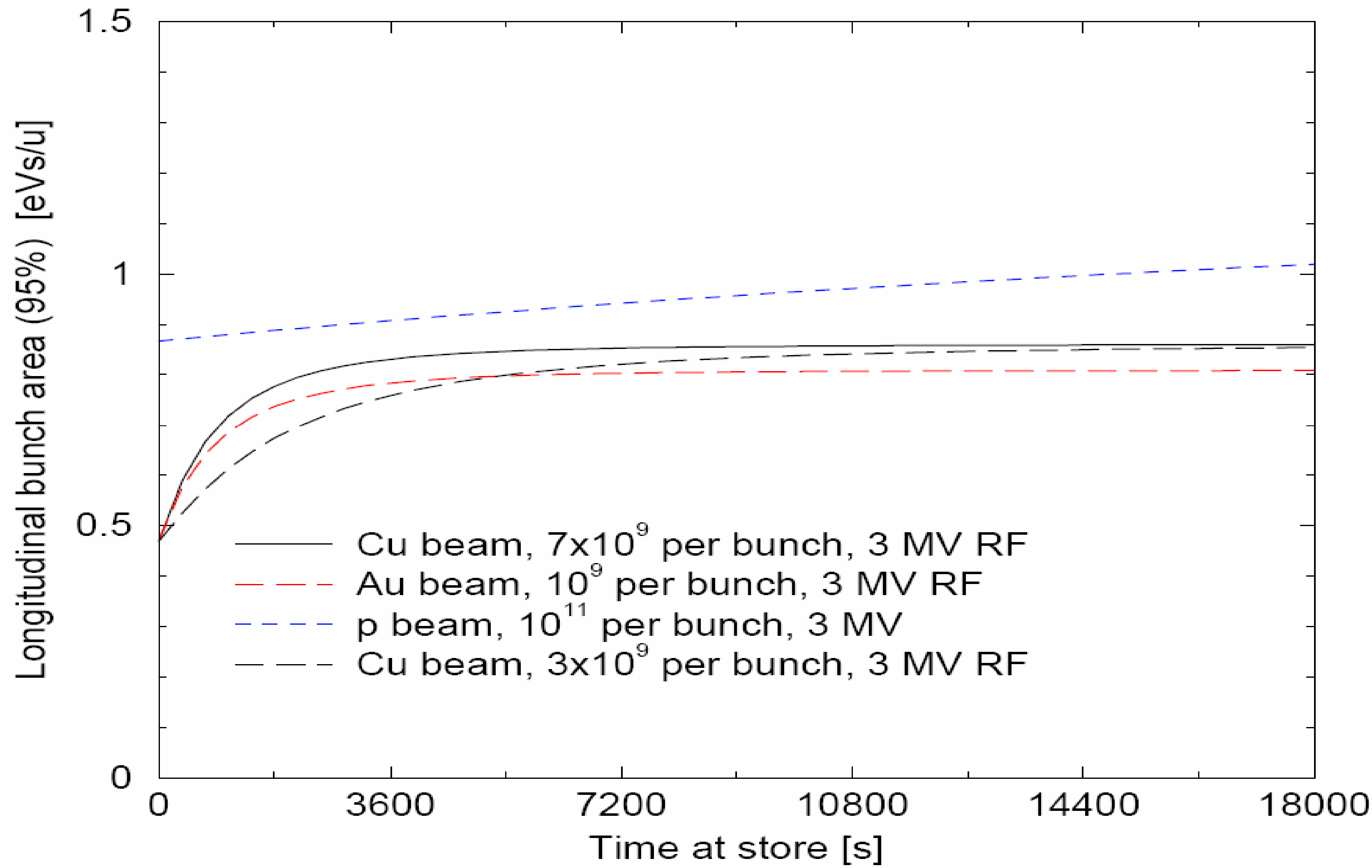
2005 Cu operation IBS prediction

- Scale with NZ^4/A^2
- 6×10^9 Cu is equivalent to 1×10^9 Au
- Can we rely on BBFP to predict the IBS behavior?

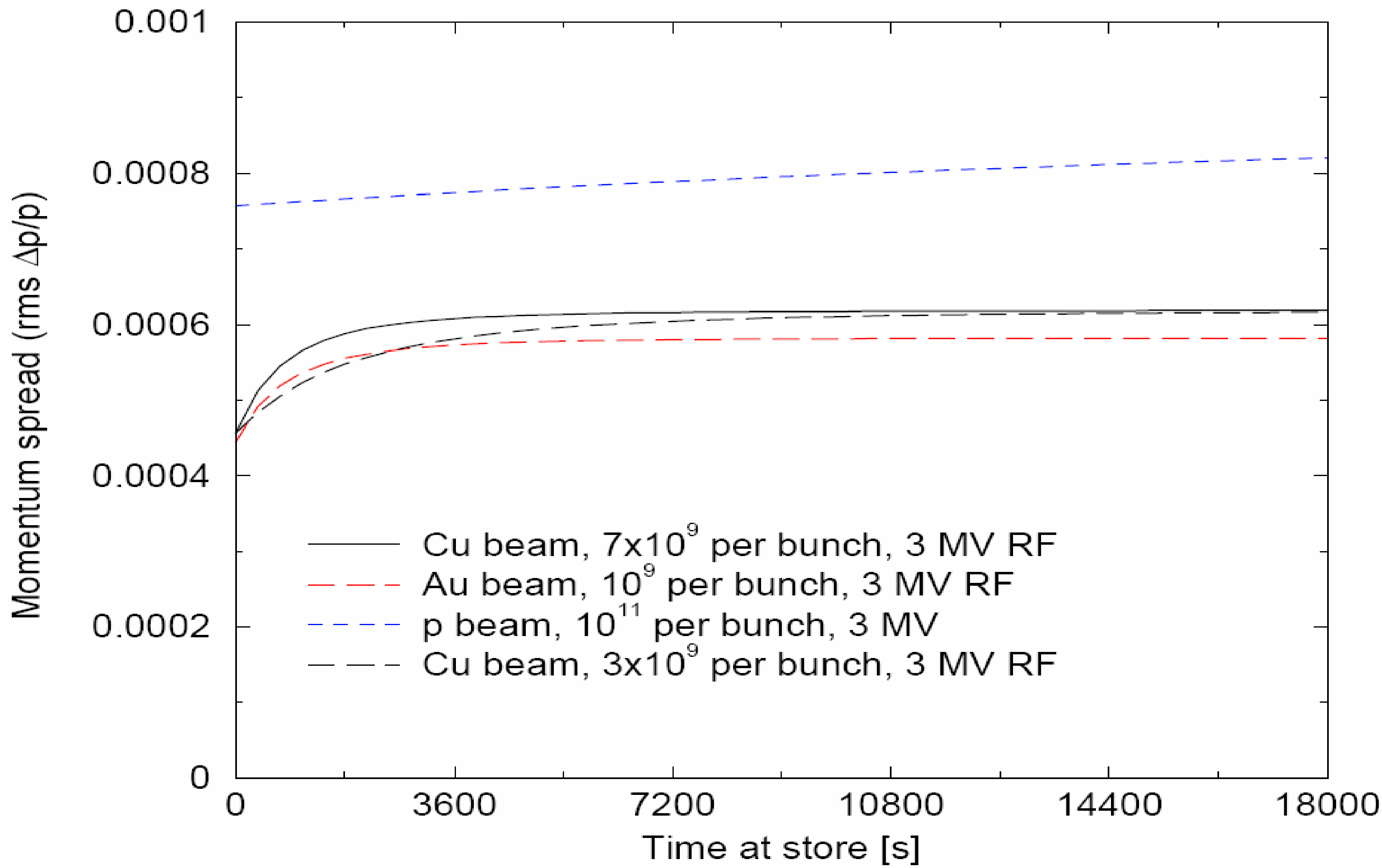
- IBS Expectation:
  - Similar behavior as Au store at 1×10^9 per bunch
  - Significant de-bunching expected; saturated bunch length and momentum spread
  - Usual rms growth prediction may not be adequate; BBFP can possibly better predict the IBS behavior

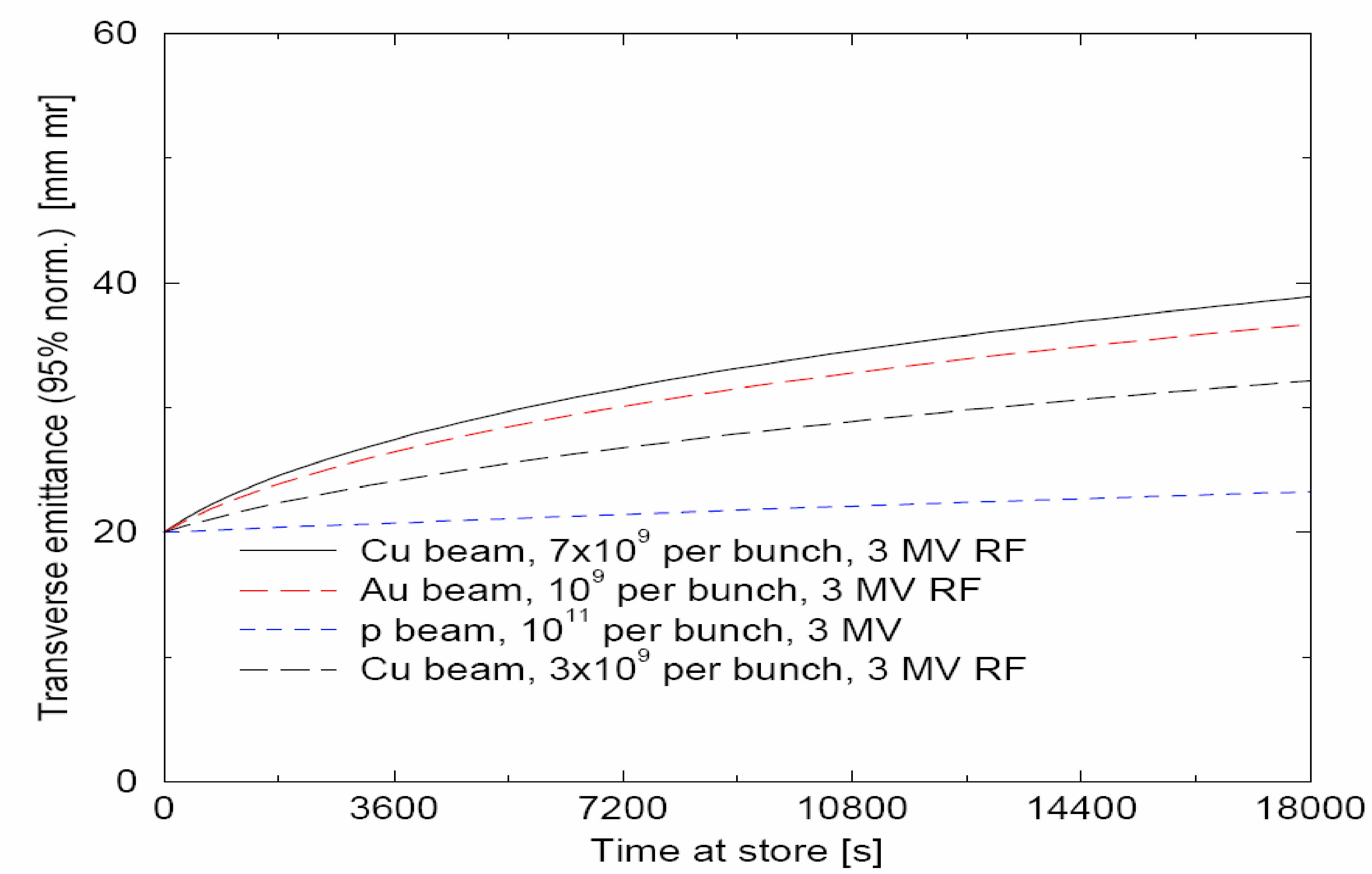


Beam survival [%]
100
80
60
40
20
0
0
3600
7200
10800
14400
18000
Time at store [s]
Cu beam, 7x10^9 per bunch, 3 MV RF
Au beam, 10^9 per bunch, 3 MV RF
p beam, 10^11 per bunch, 3 MV
Cu beam, 3x10^9 per bunch, 3 MV

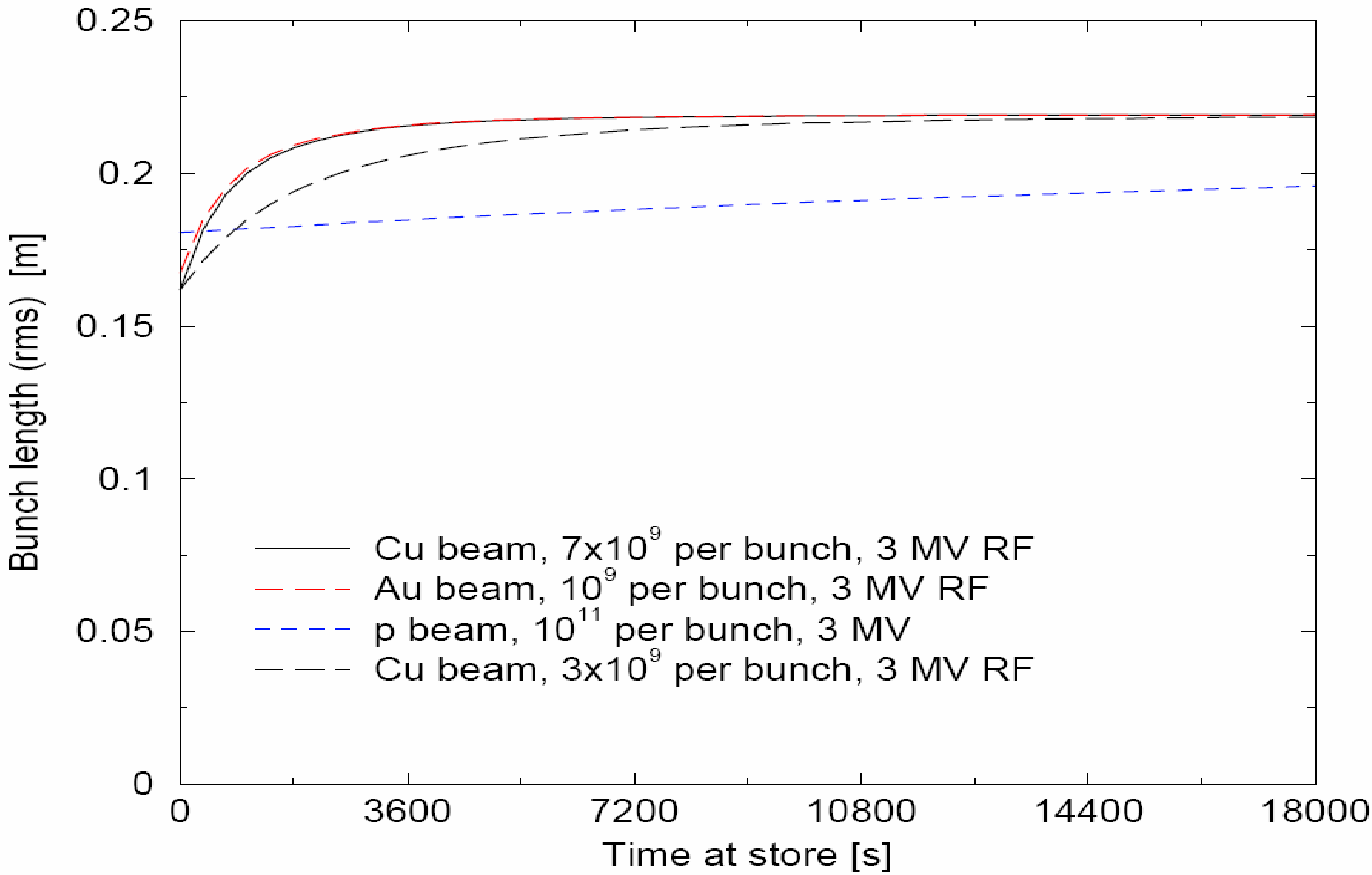


1.5
1
0.5
0
Longitudinal bunch area (95%) [eVs/u]
0
3600
7200
10800
14400
18000
Time at store [s]
Cu beam, 7x10^9 per bunch, 3 MV RF
Au beam, 10^9 per bunch, 3 MV RF
p beam, 10^11 per bunch, 3 MV
Cu beam, 3x10^9 per bunch, 3 MV RF

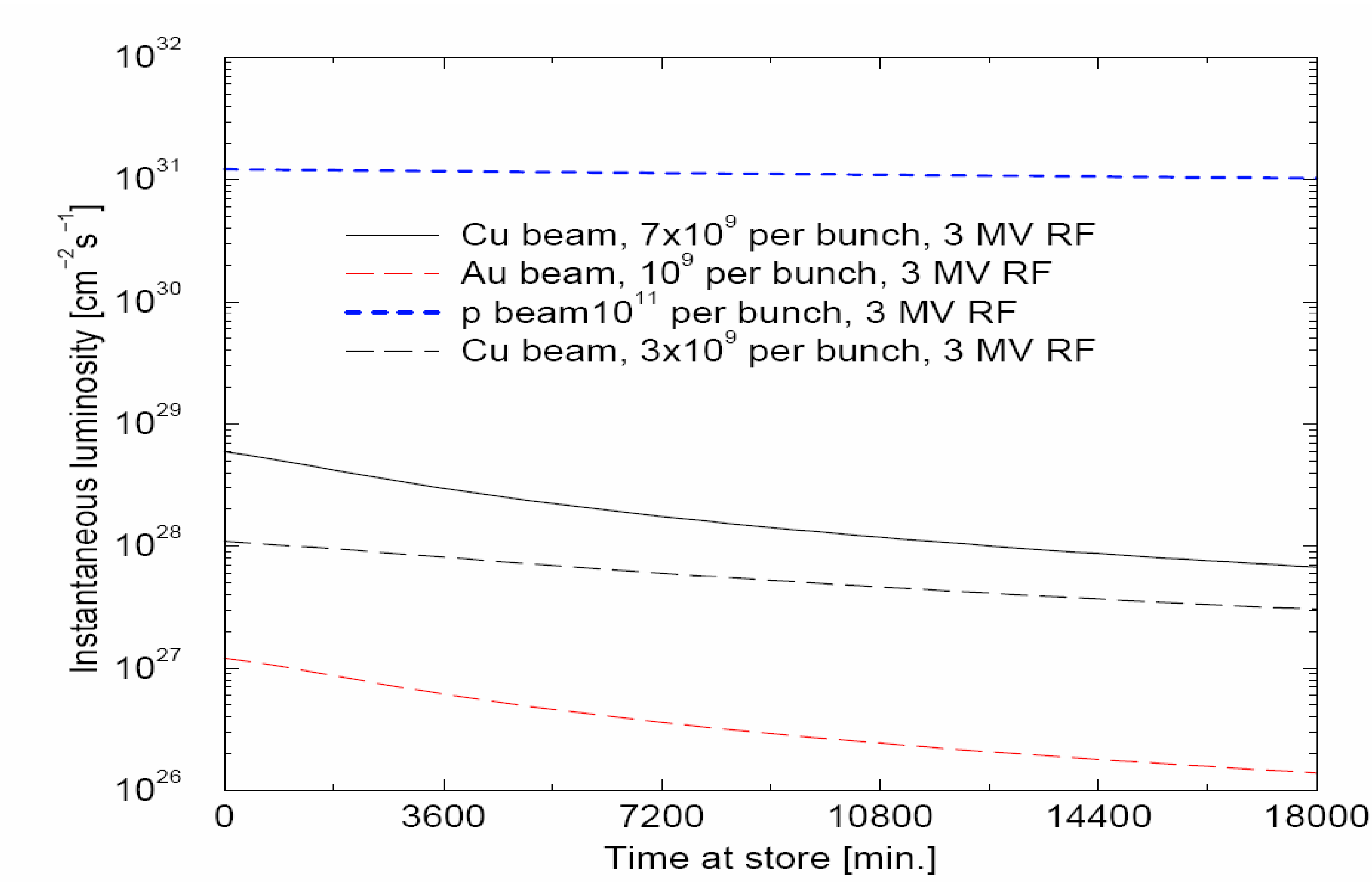

0.001
0.0008
0.0006
0.0004
0.0002
0
0
3600
7200
10800
14400
18000
Time at store [s]
Momentum spread (rms Δp/p)
Cu beam, 7x10^9 per bunch, 3 MV RF
Au beam, 10^9 per bunch, 3 MV RF
p beam, 10^11 per bunch, 3 MV
Cu beam, 3x10^9 per bunch, 3 MV RF



60
40
20
0
0
3600
7200
10800
14400
18000
Time at store [s]
Transverse emittance (95% norm.) [mm mr]
Cu beam, 7x10^9 per bunch, 3 MV RF
Au beam, 10^9 per bunch, 3 MV RF
p beam, 10^11 per bunch, 3 MV
Cu beam, 3x10^9 per bunch, 3 MV RF



0.25
0.2
0.15
0.1
0.05
0
Bunch length (rms) [m]
0
3600
7200
10800
14400
18000
Time at store [s]
Cu beam, 7x10⁹ per bunch, 3 MV RF
Au beam, 10⁹ per bunch, 3 MV RF
p beam, 10¹¹ per bunch, 3 MV
Cu beam, 3x10⁹ per bunch, 3 MV RF



10^{32}
10^{31}
10^{30}
10^{29}
10^{28}
10^{27}
10^{26}
Instantaneous luminosity [$cm^{-2}s^{-1}$]
Cu beam, $7x10^9$ per bunch, 3 MV RF
Au beam, 10^9 per bunch, 3 MV RF
p beam10^{11} per bunch, 3 MV RF
Cu beam, $3x10^9$ per bunch, 3 MV RF
0
3600
7200
10800
14400
18000
Time at store [min.]

Comparison of IBS models for RHIC

A. Fedotov, G. Trubnikov and J. Wei

August 2004

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Simulations - Models

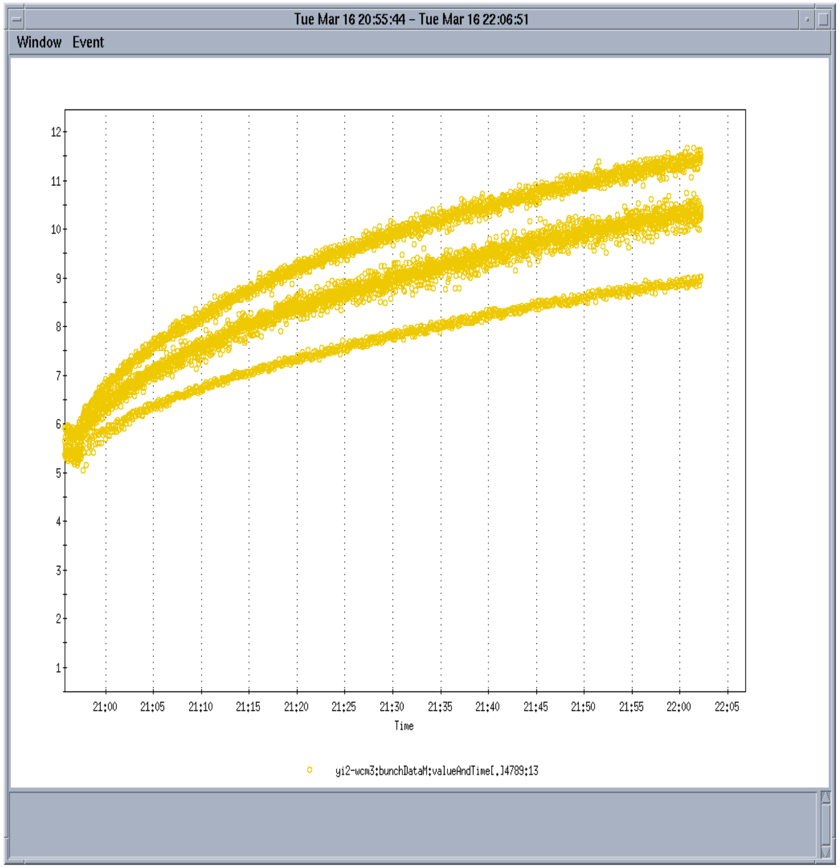
Various models for IBS were implemented in BetaCool code:

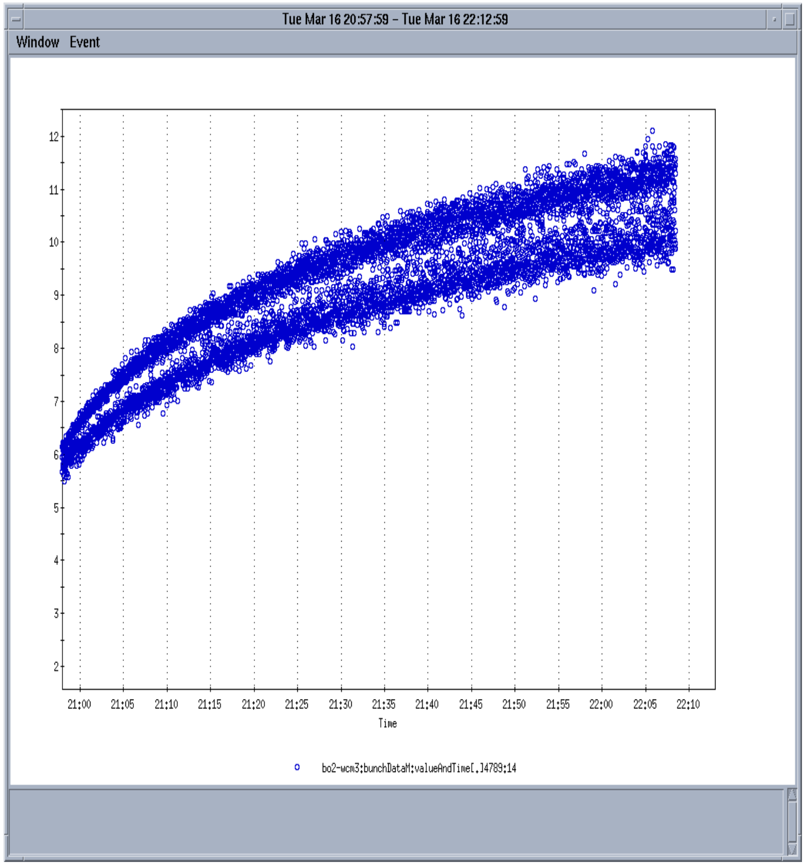
Piwinsky, Martini, Bjorken-Mtingwa, Wei, plasma-relaxation

- Benchmarking of various models was presented (November'2003, January'2004) at e-cooling meetings (Fedotov, Trubnikov et al).

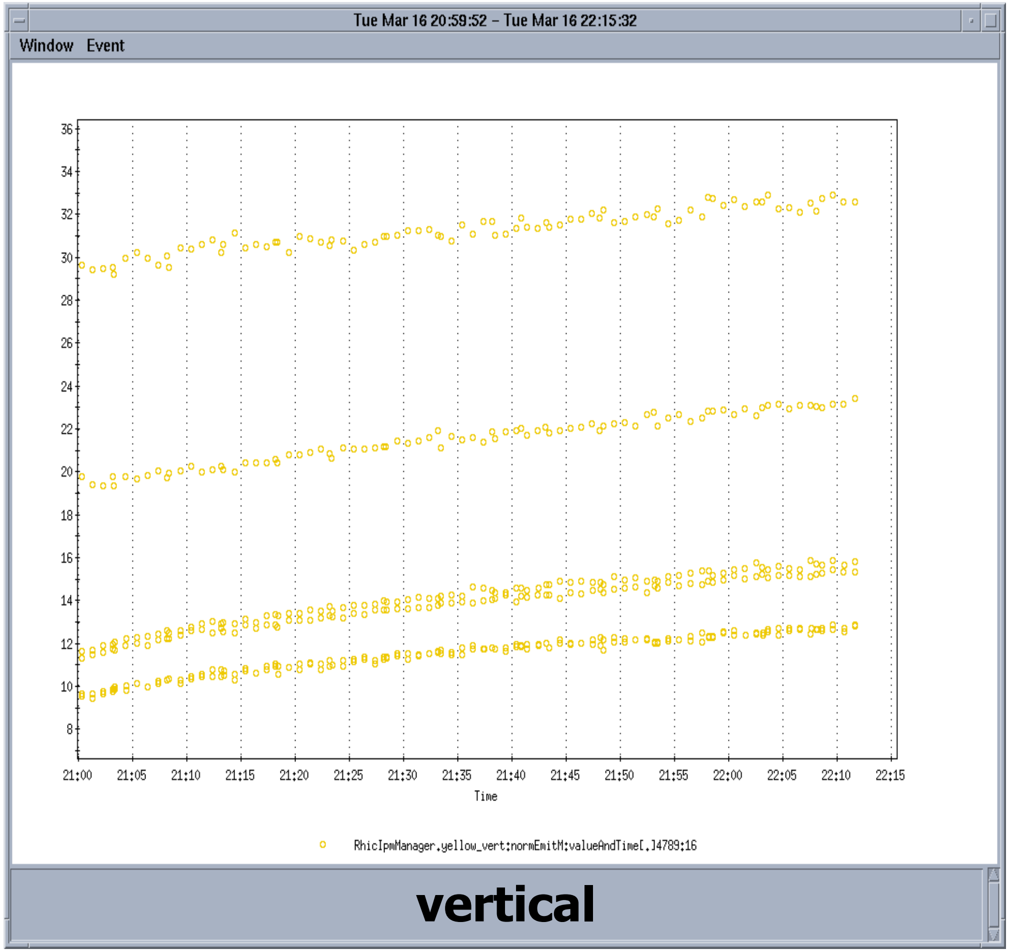
- Here, difference between models is shown using the data from dedicated IBS experiment (March 16, 2004).

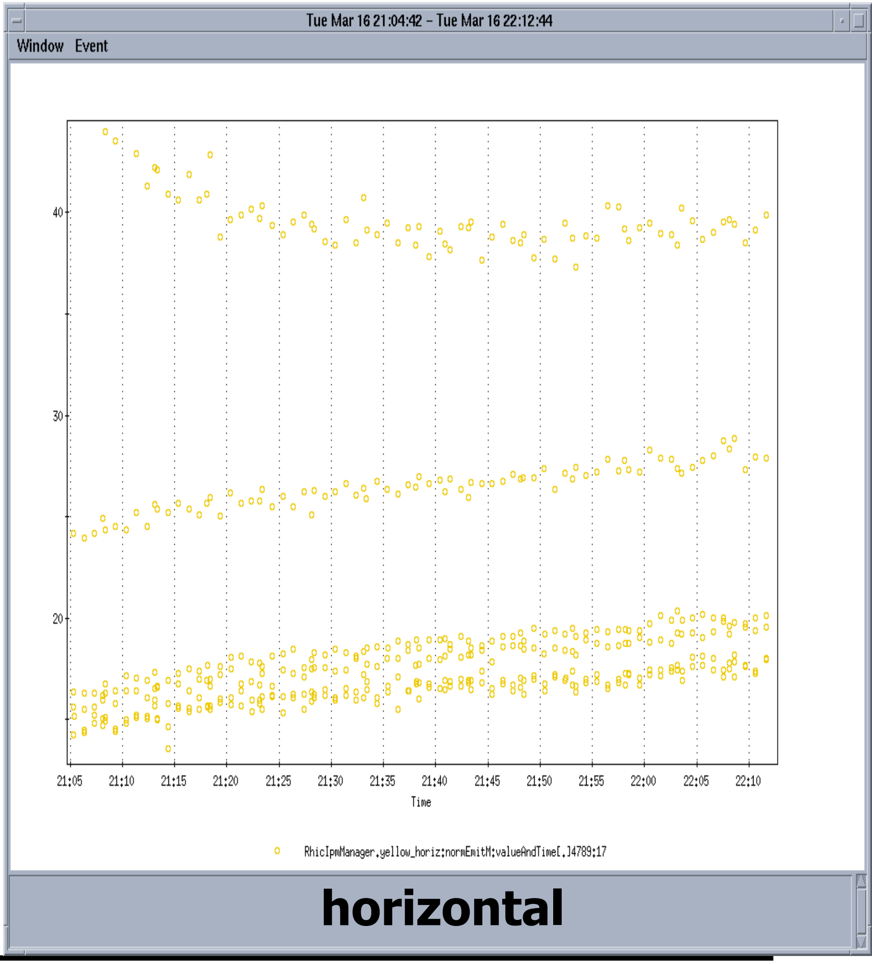
Longitudinal bunch length growth - measurements





Yellow: Transverse emittance growth – IPM measurements





Example of IBS growth from measurement

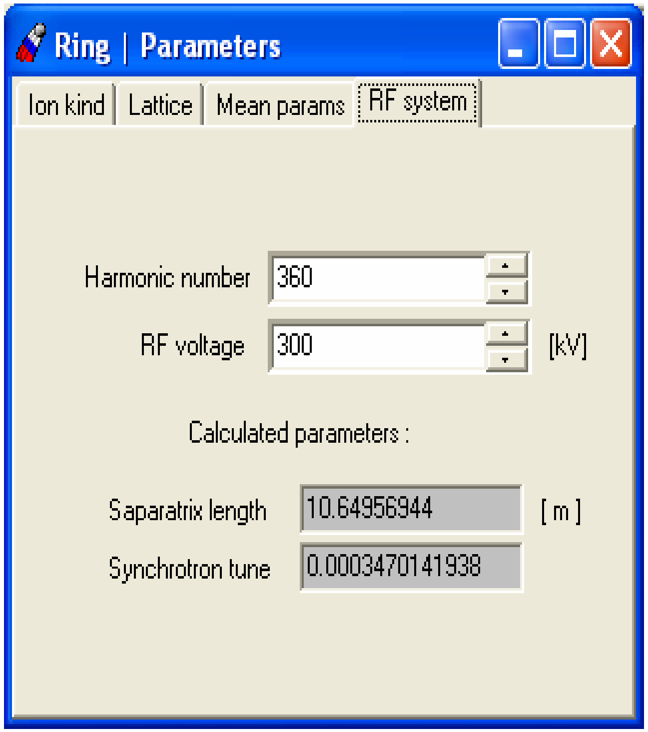
Measurements

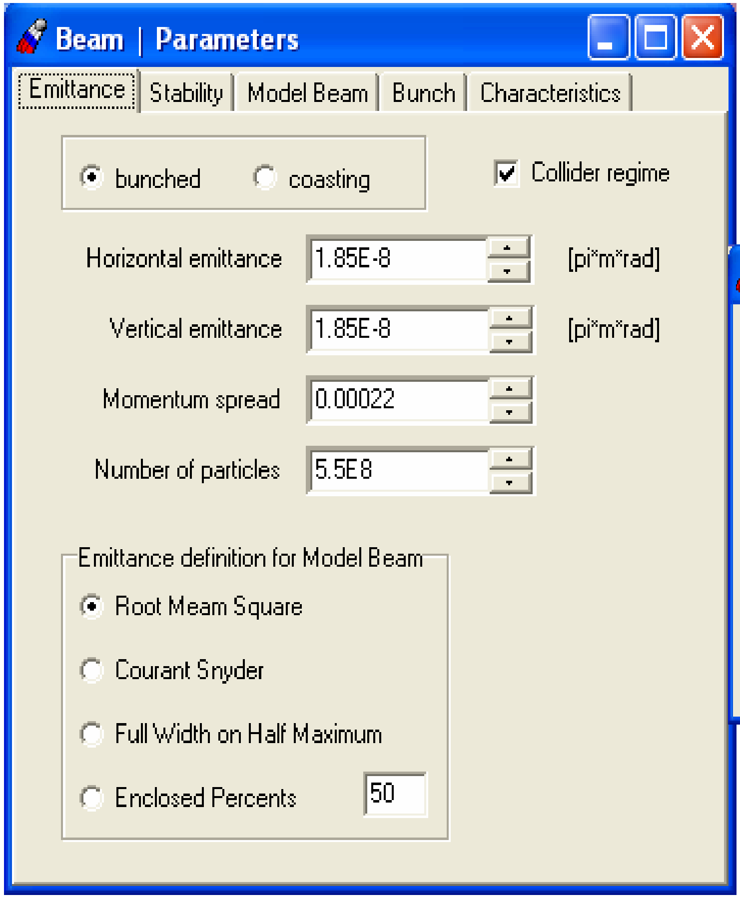
Bucket with N=0.55*10^9:

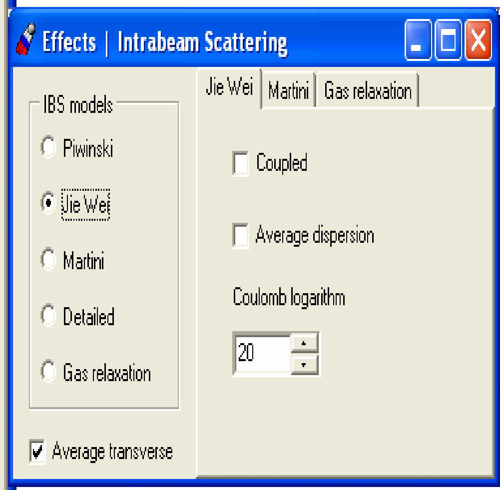
Emittance growth: 25-30% in 1 hours

Bunch length: about 80% growth in 1 hour

Simulation parameters

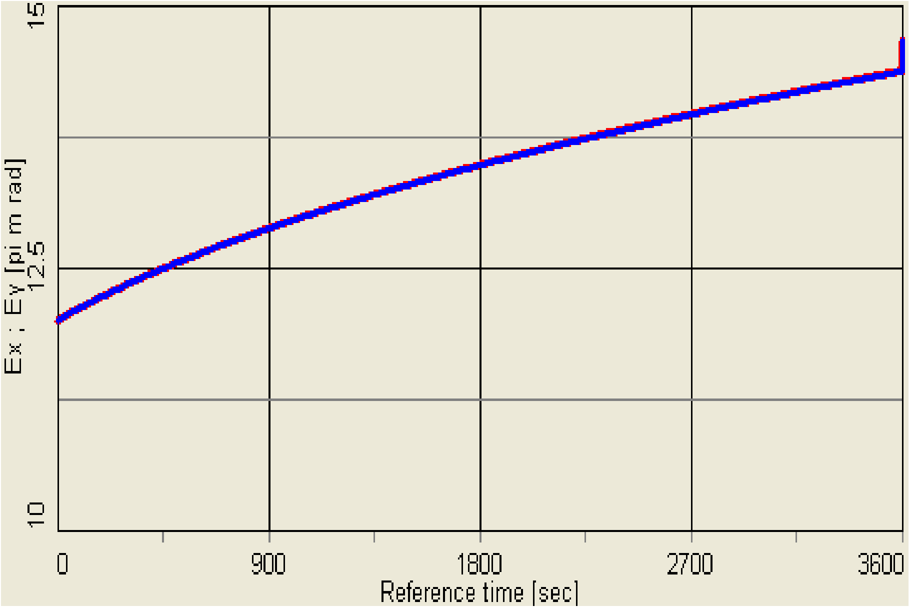


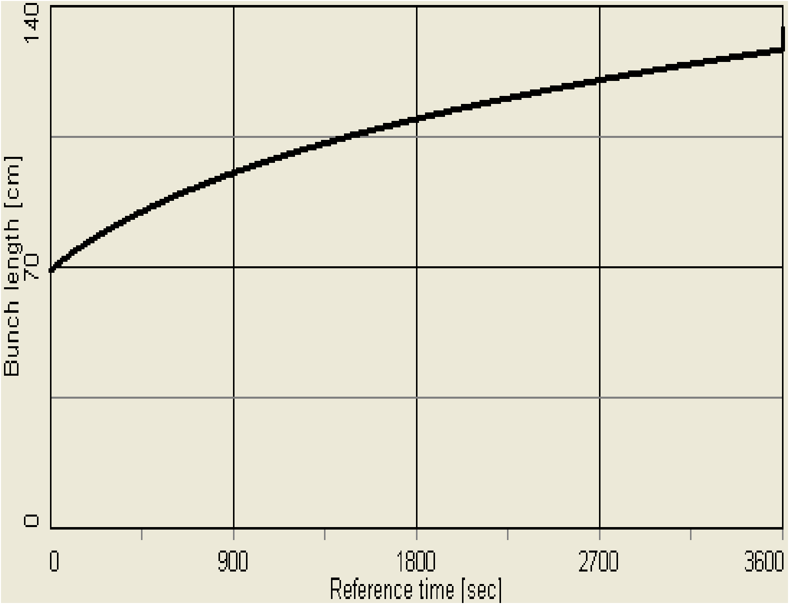




1. First effect in emittance growth - dispersion

FODO approximation with higher average dispersion

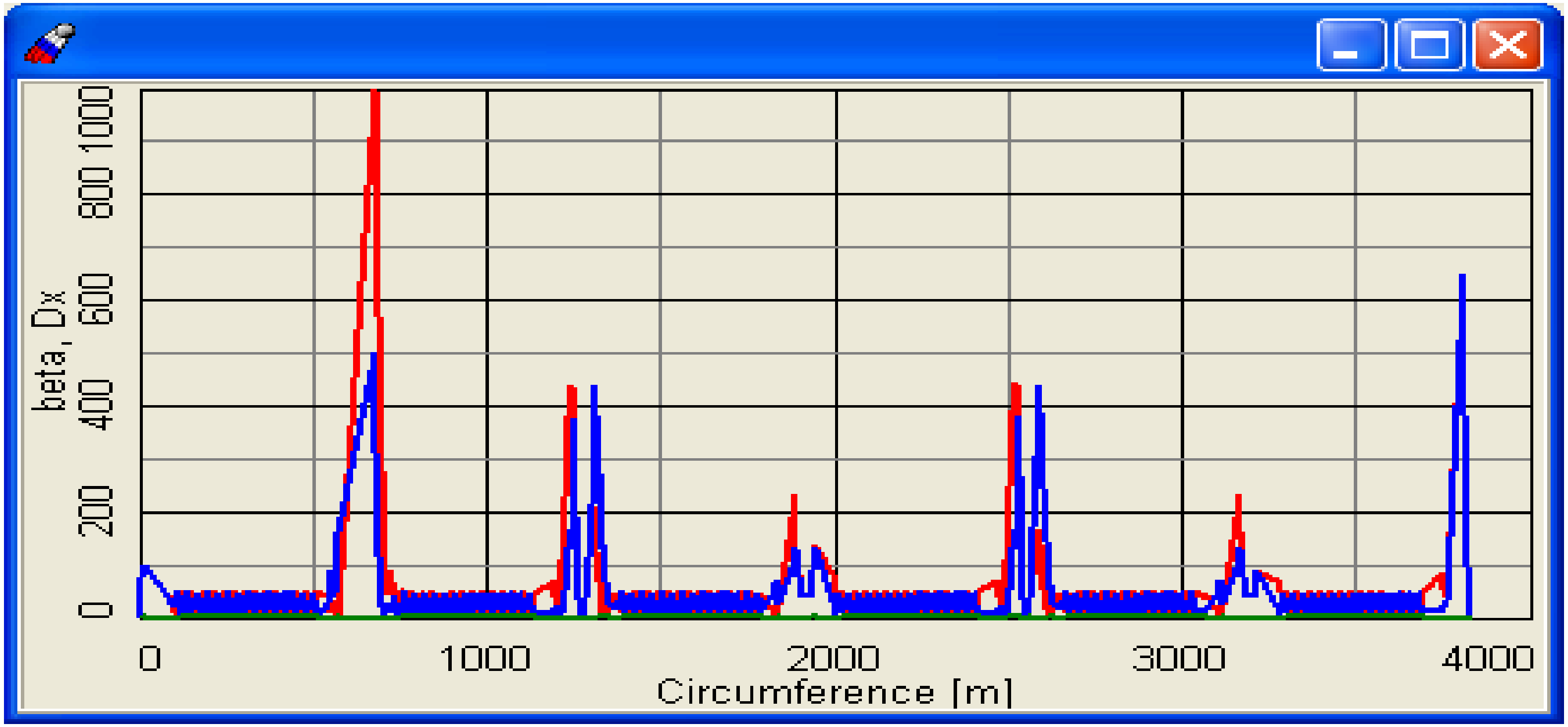




20% growth

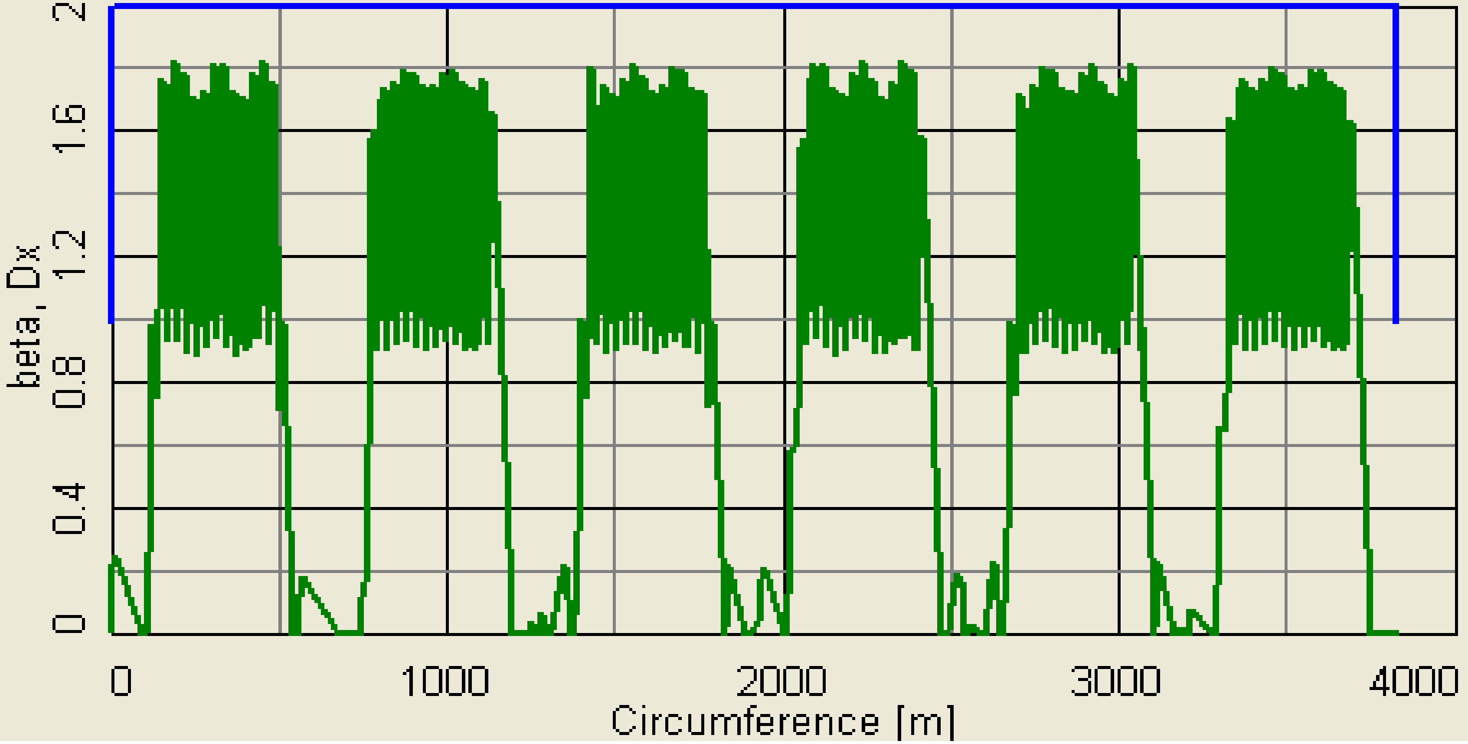
86% growth

RHIC-4 mad lattice: beta-functions

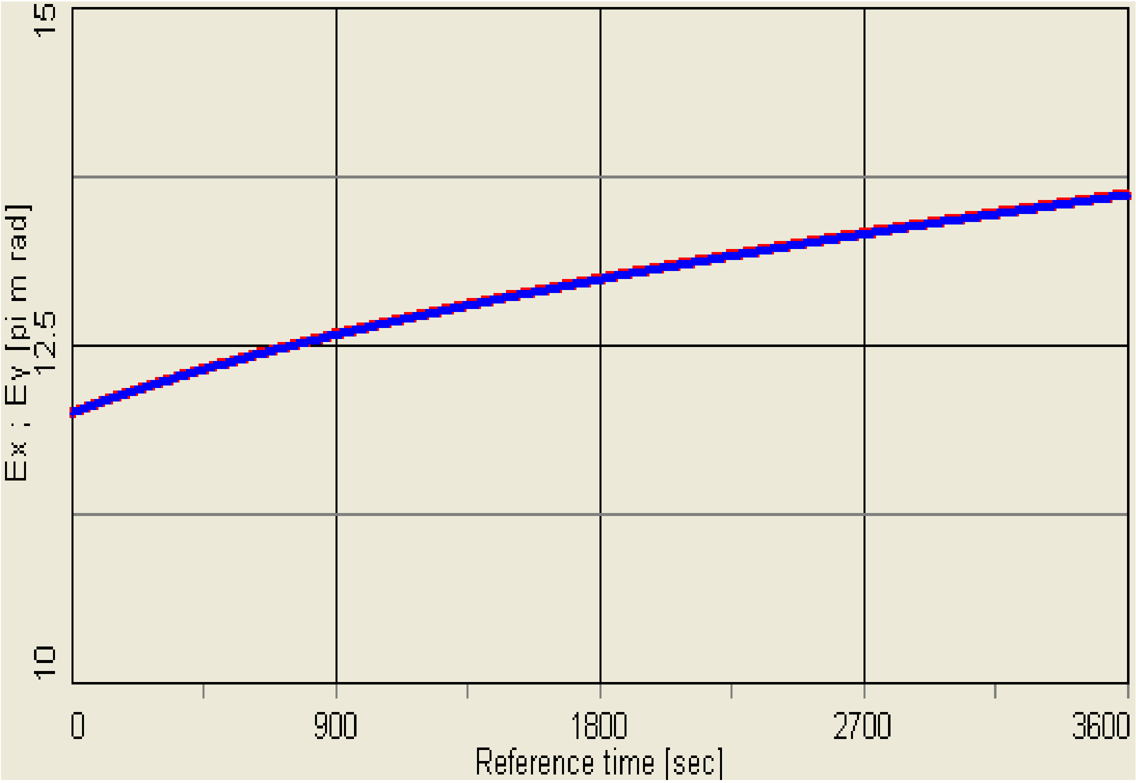


More realistic lattice gives lower average dispersion and low emittance growth

RHIC-4 lattice: dispersion

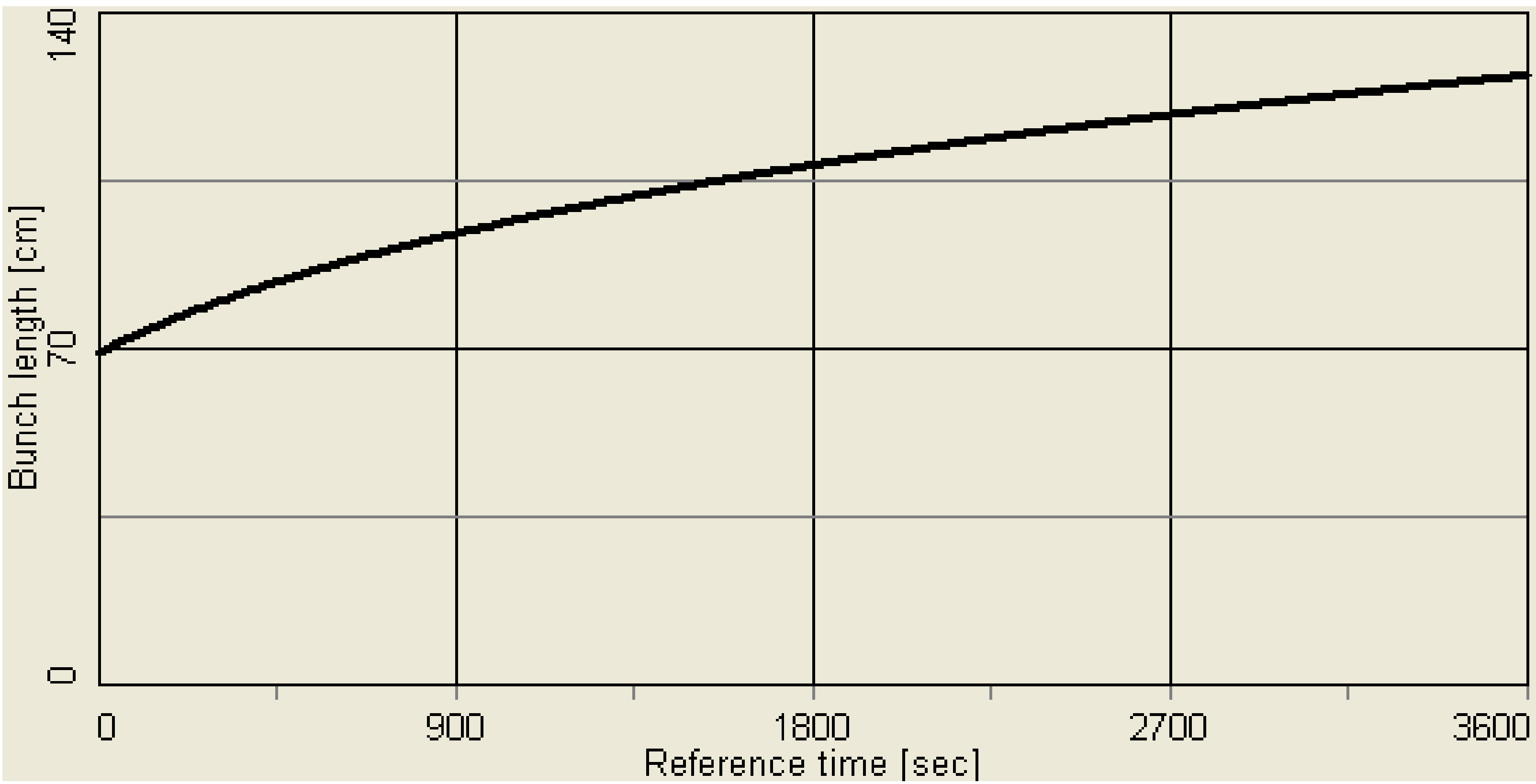


J.Wei formula (not high-energy approximation) with element-by-element IBS

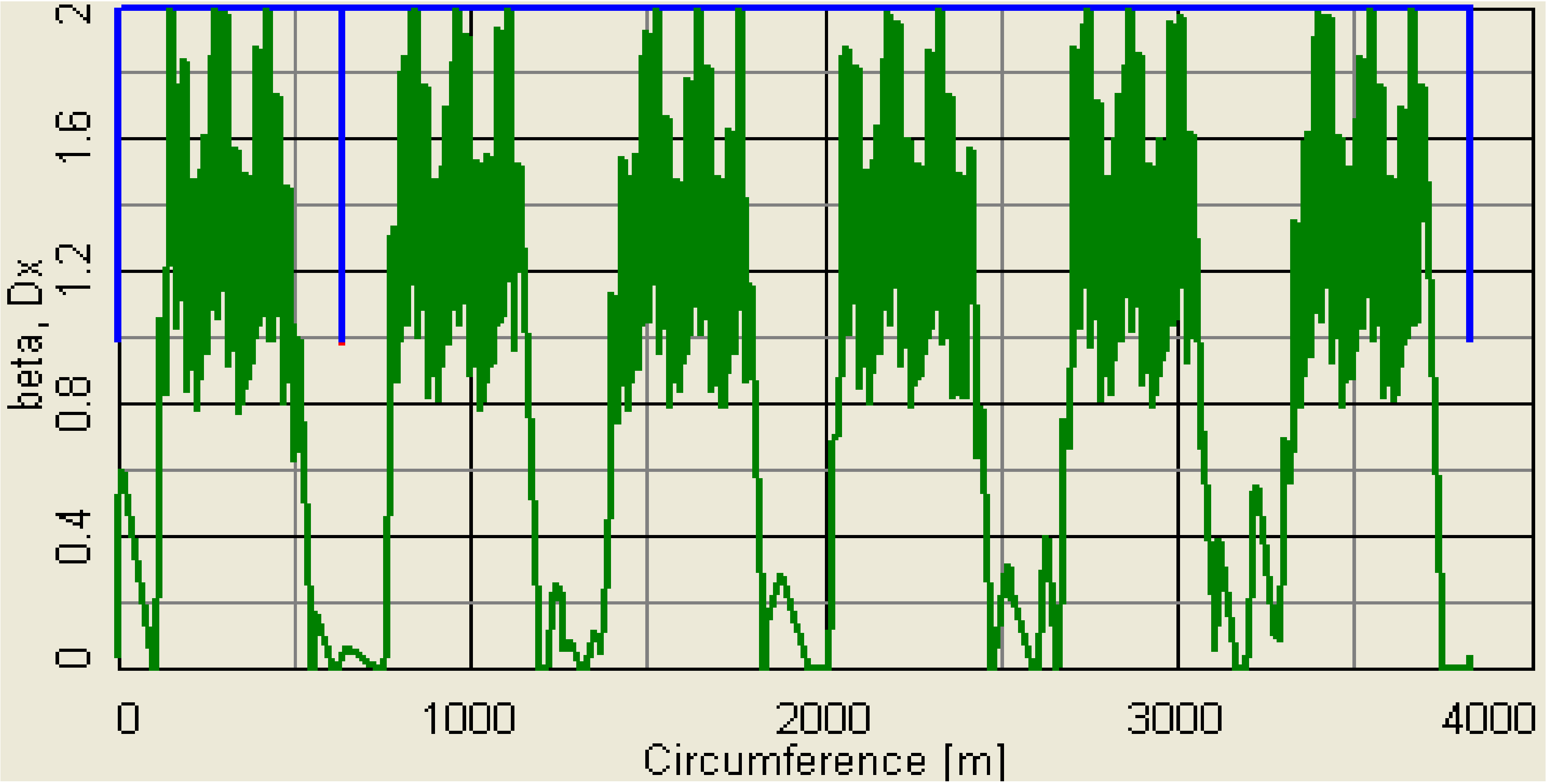


13% growth

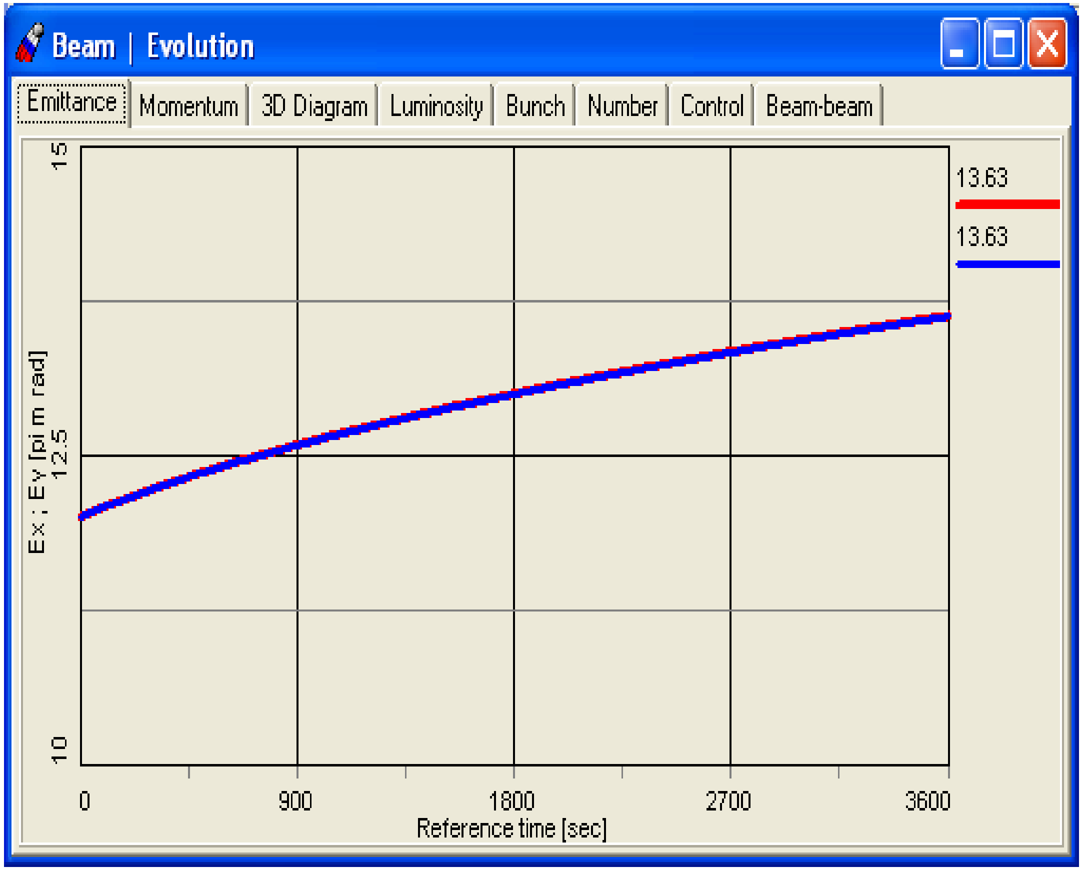
J. Wei formula (not high energy approximation) with element-by-element IBS



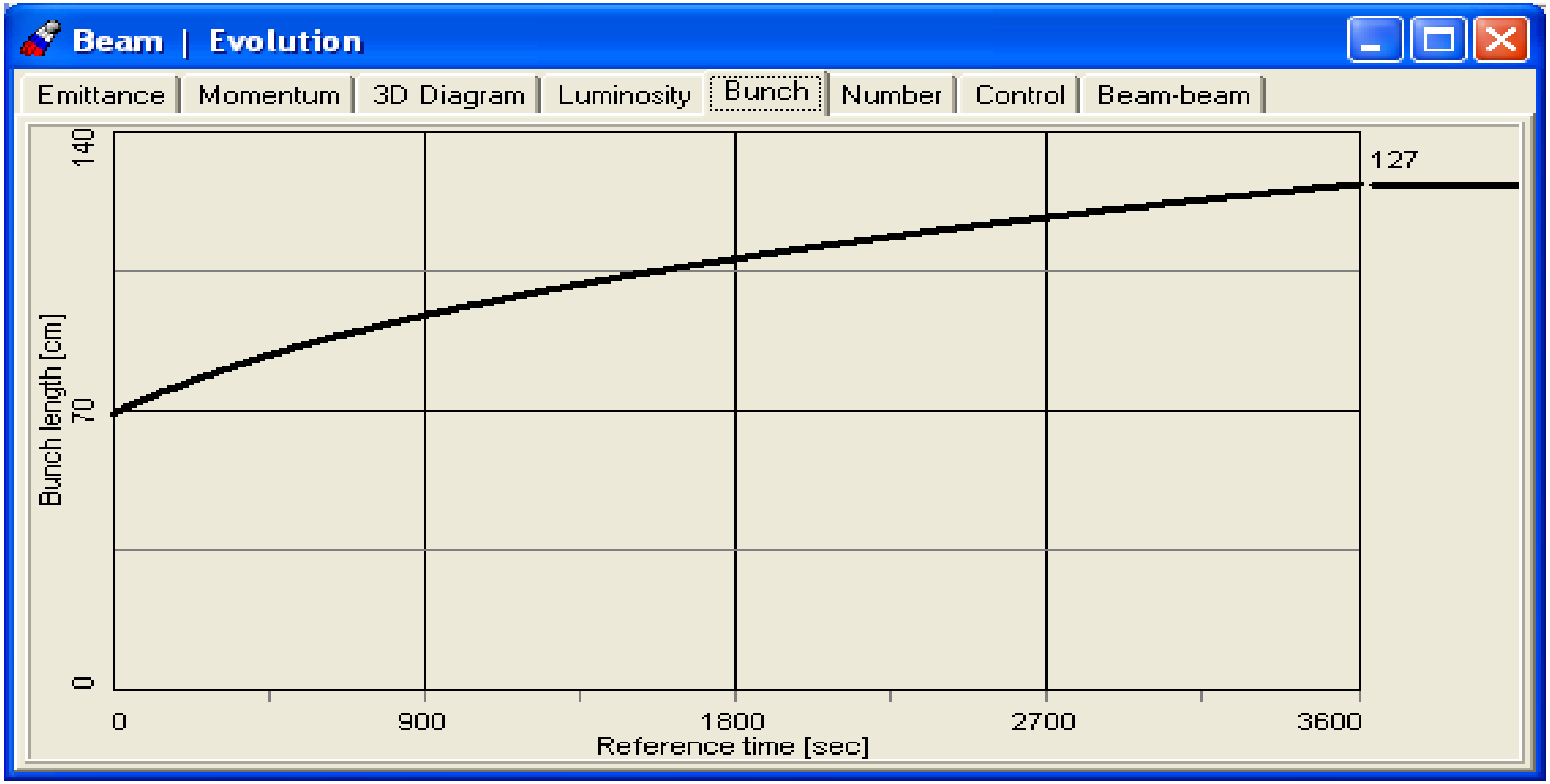
J. Wei formula (not high energy approximation) with element-by-element IBS



J. Wei formula (not high energy approximation) with element-by-element IBS



13-14% growth



Beam | Evolution
Emittance
Momentum
3D Diagram
Luminosity
Bunch
Number
Control
Beam-beam
140
70
0
Bunch length [cm]
127
0
900
1800
2700
3600
Reference time [sec]

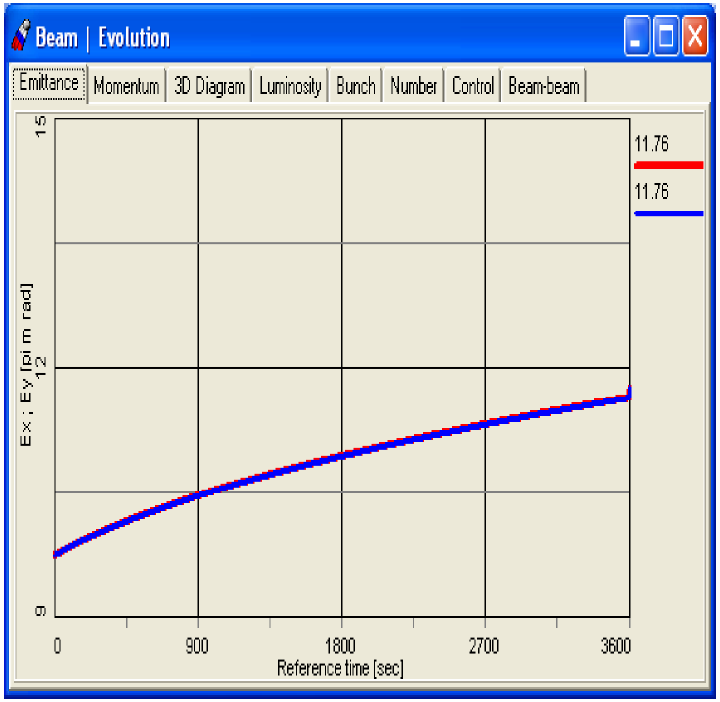
Differences between FODO approximation and real lattice

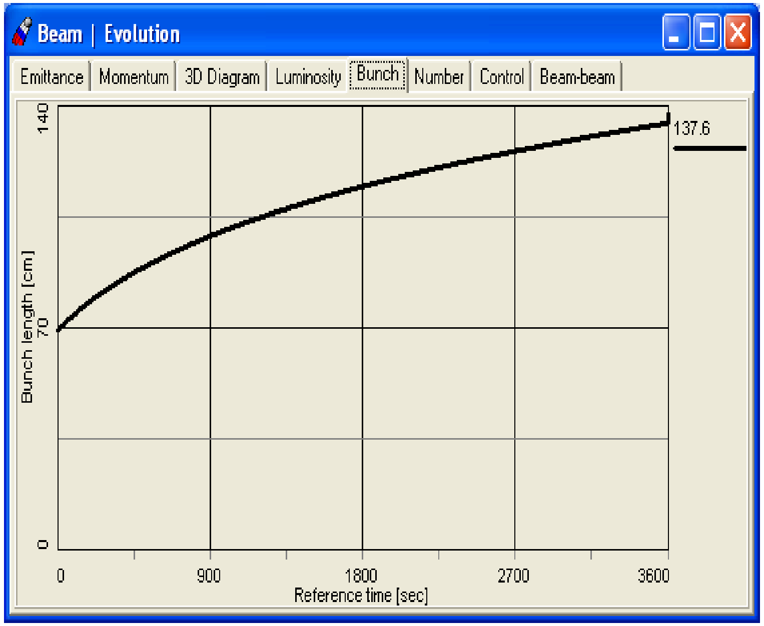
- FODO approximation assumes that transverse emittance growth happens through the whole ring.

- Real lattice with element-by-element tracking takes into account that there is no contribution in transverse emittance growth in straight sections – additional factor

“total arc length/circumference”

2. Second effect: absolute values of initial emittance/IPM calibration





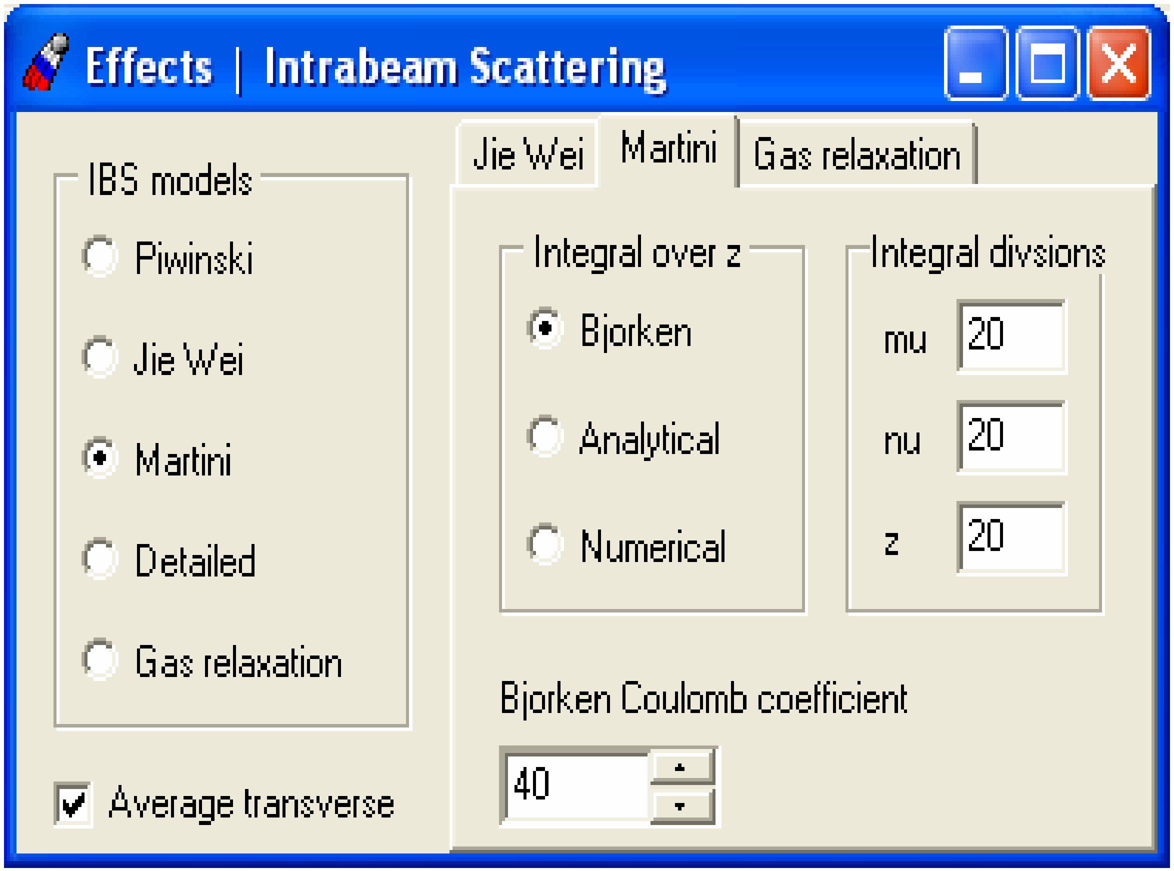
Emittance growth 13%->20% if initial emittance is 20% smaller

Different models

Martini/ Bjorken-Mtingwa models give smaller emittance

growth by about 30-40% compared to Wei models

when realistic RHIC lattice is used and IBS is calculated at each element.



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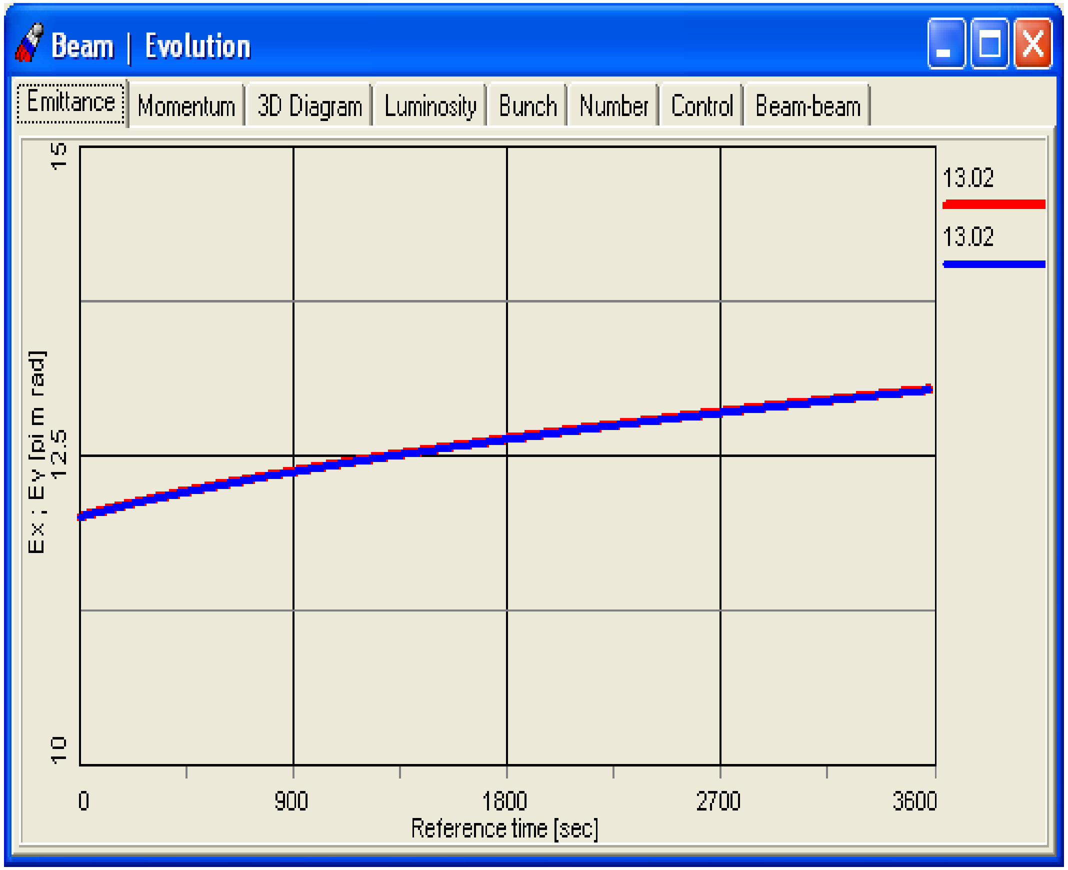
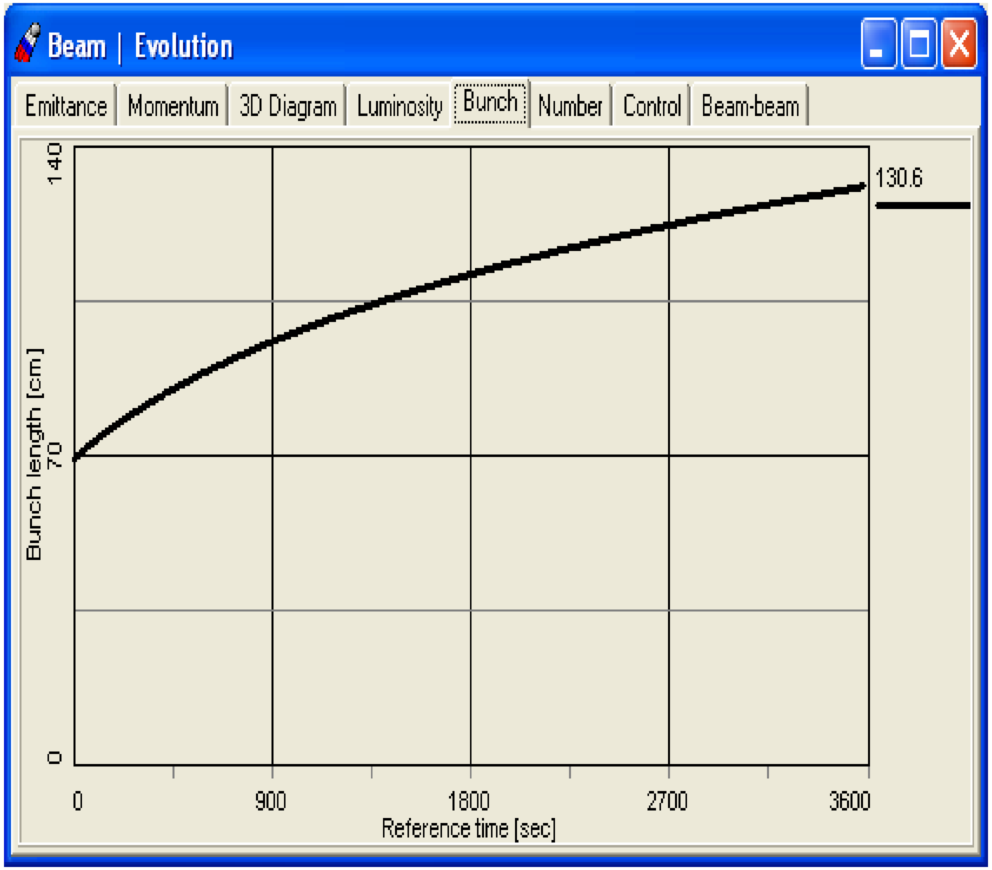
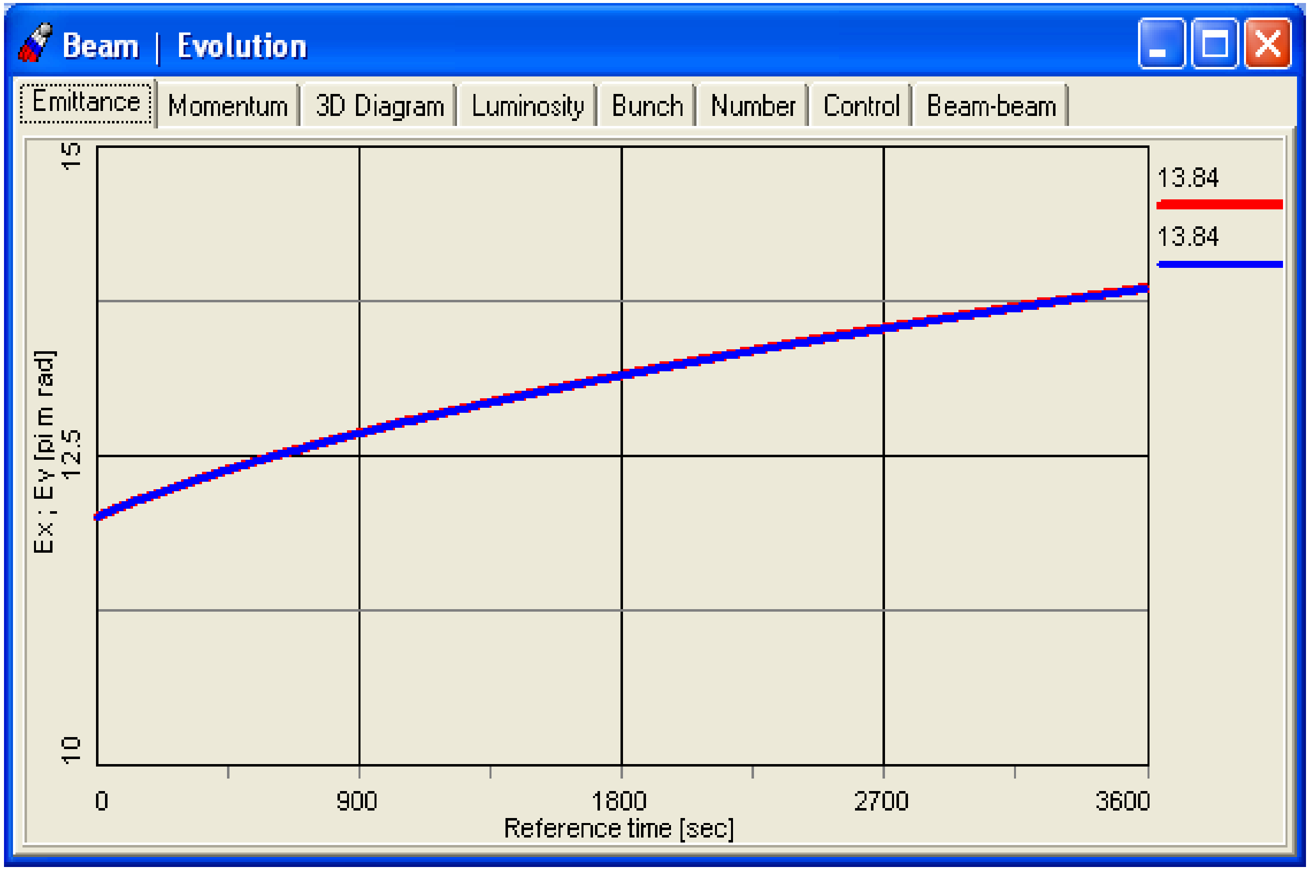
Martini (B-M): real lattice



Martini (B-M): real lattice



Martini: FODO lattice with higher dispersion



Simulation results

- Realistic RHIC lattice:

Martini (numerical):	emittance:	9% growth
	bunch length:	86% growth
Martini (Bjorken-Mtingwa):	emittance:	9% growth
	bunch length:	86% growth
Wei (F(x) function):	emittance	13% growth
	bunch length:	81% growth

- FODO lattice with higher average dispersion:

Martini/B-M:	emittance:	15% growth
Wei:	emittance:	20% growth
	bunch length:	86% growth

Results

Emittance growth:

1. Strong dependence on average dispersion:

 can vary from 10-20% - gives up to factor of 2 uncertainty

Need an accurate estimate of dispersion and dispersion wave

(Johannes promised to get an estimate from online model)

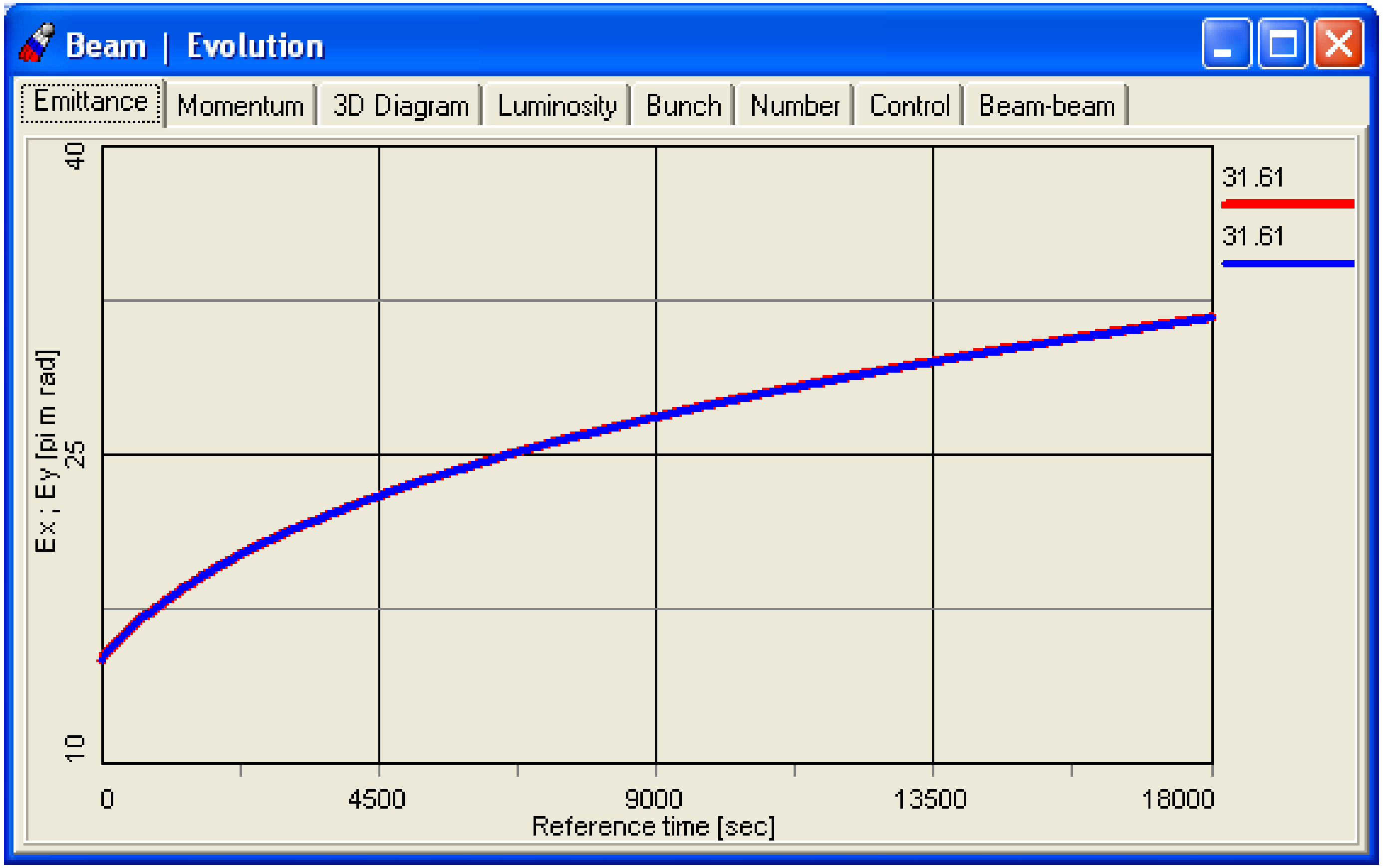
2. Calibration of IPM at store (was done only for lattice at injection):

20 % change in initial emittance values change

Emittance growth in 1 hour from 13% to 20%

 Within such large margin of uncertainty using both 1 & 2 on can fit experimentally observed emittance growth even using element-by-element IBS model.

Standard RHIC store conditions
(RHIC-4 Au run at 100 GeV), J.Wei (FODO approx.)



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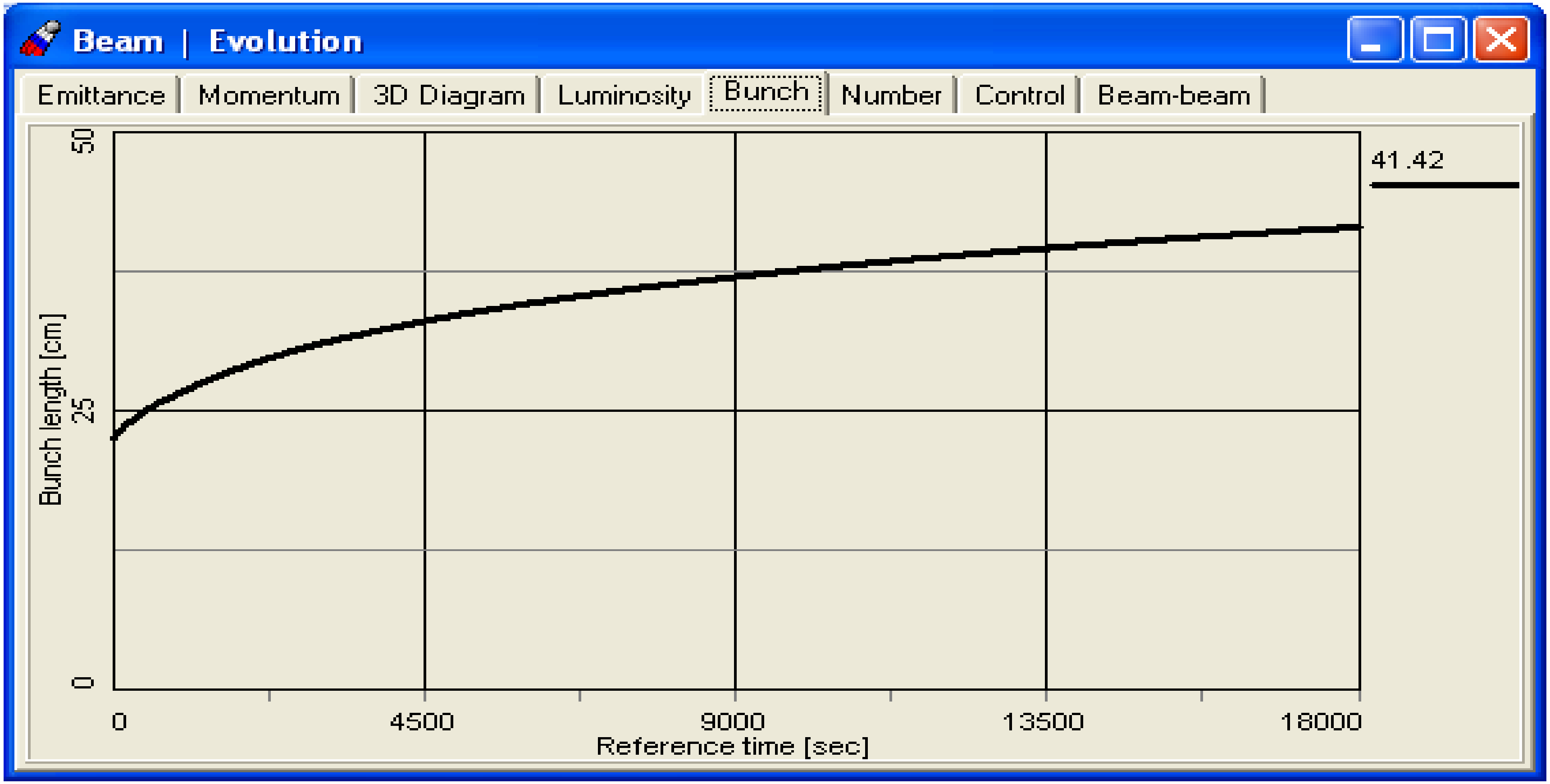
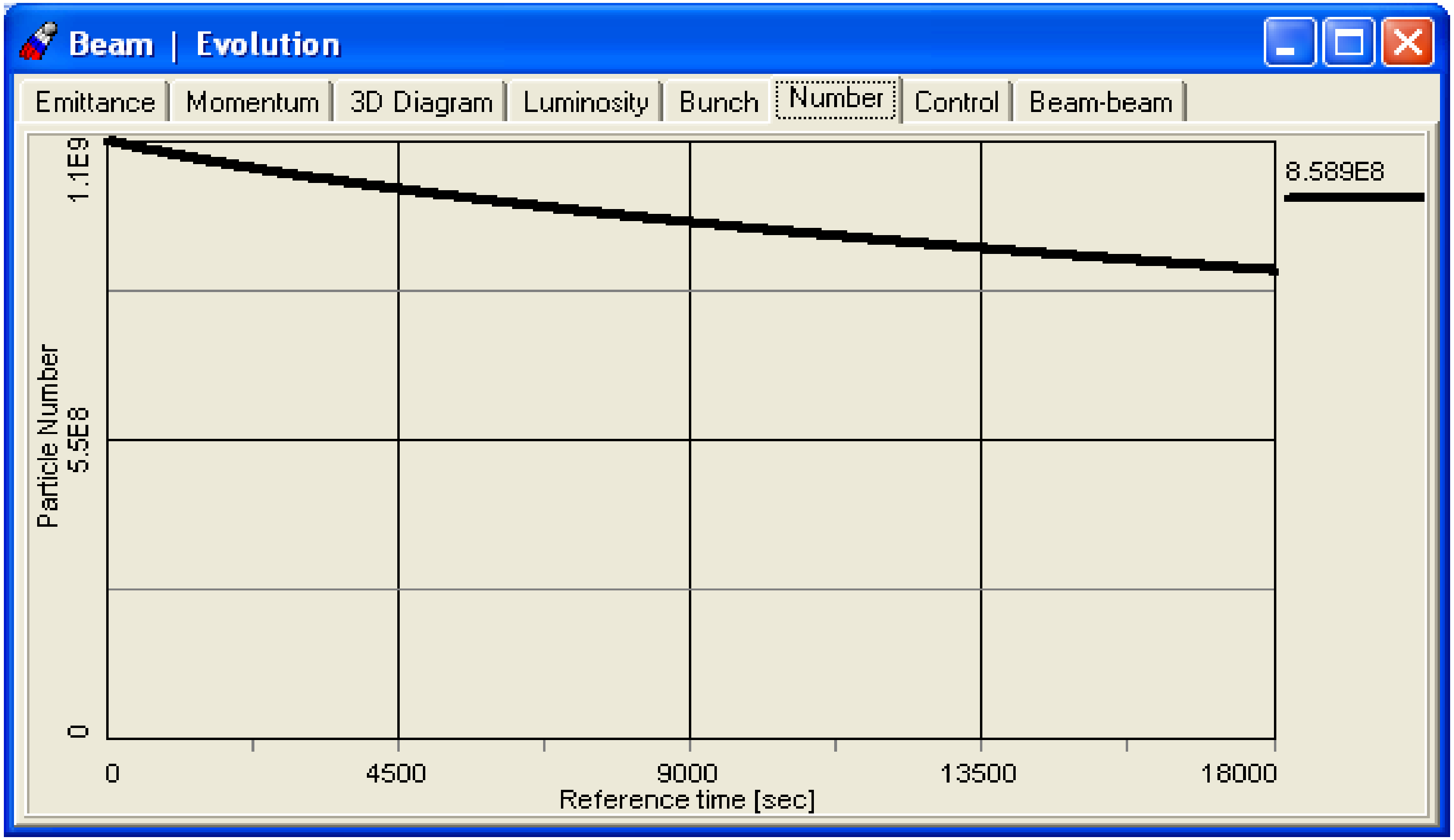
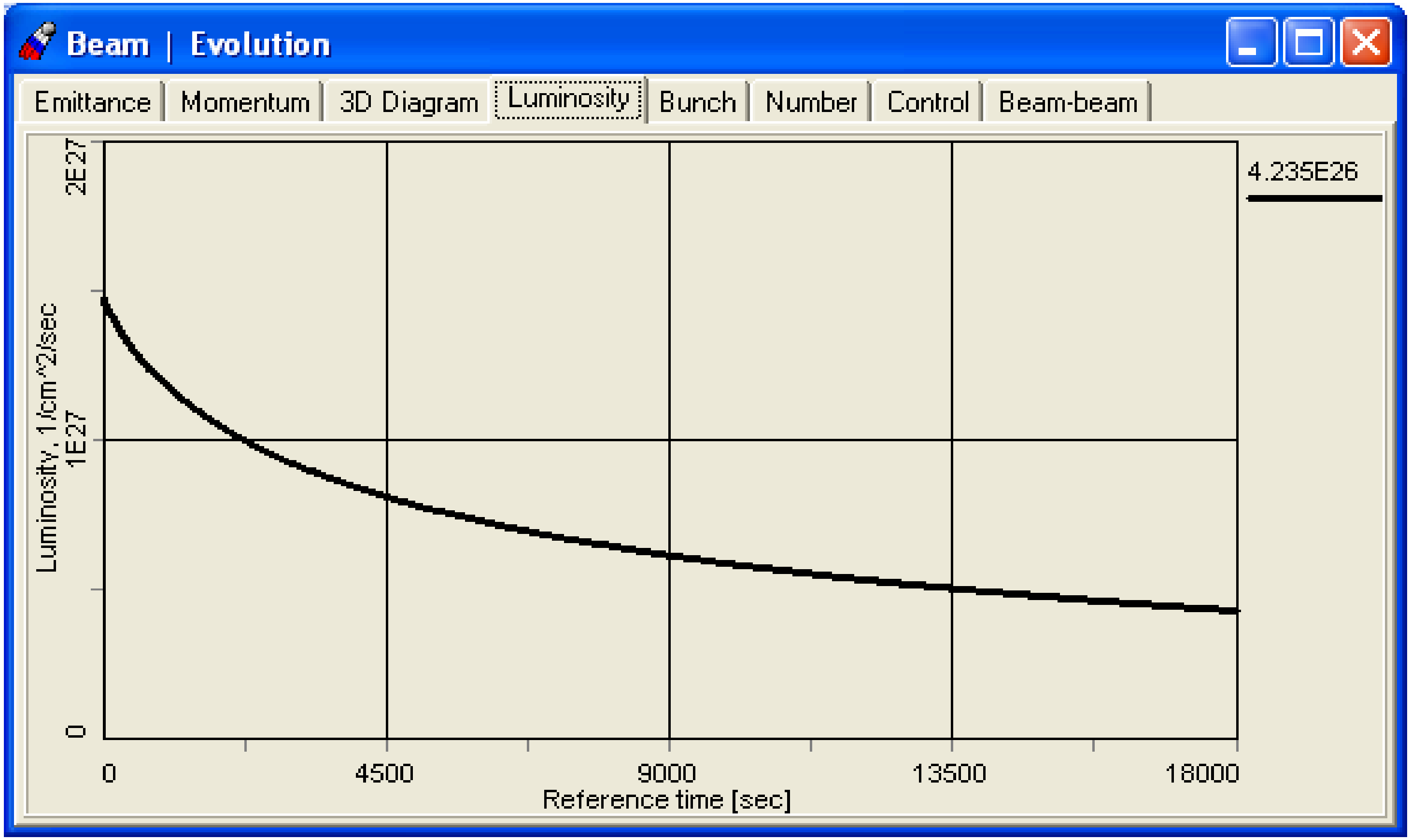
J.Wei (FODO approx.)



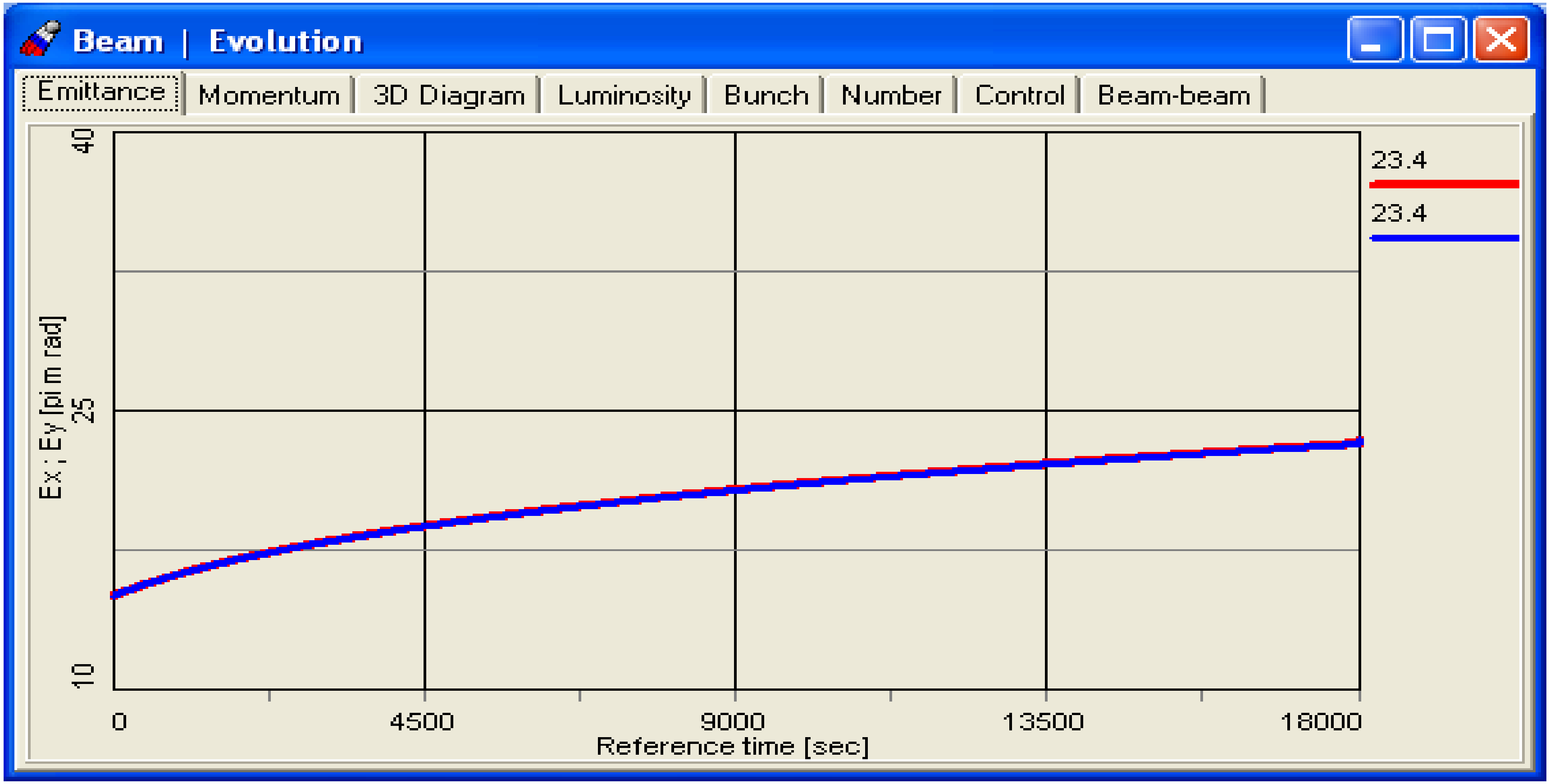
J.Wei (FODO approx.)



J.Wei (FODO approx.)



Martini (real lattice)



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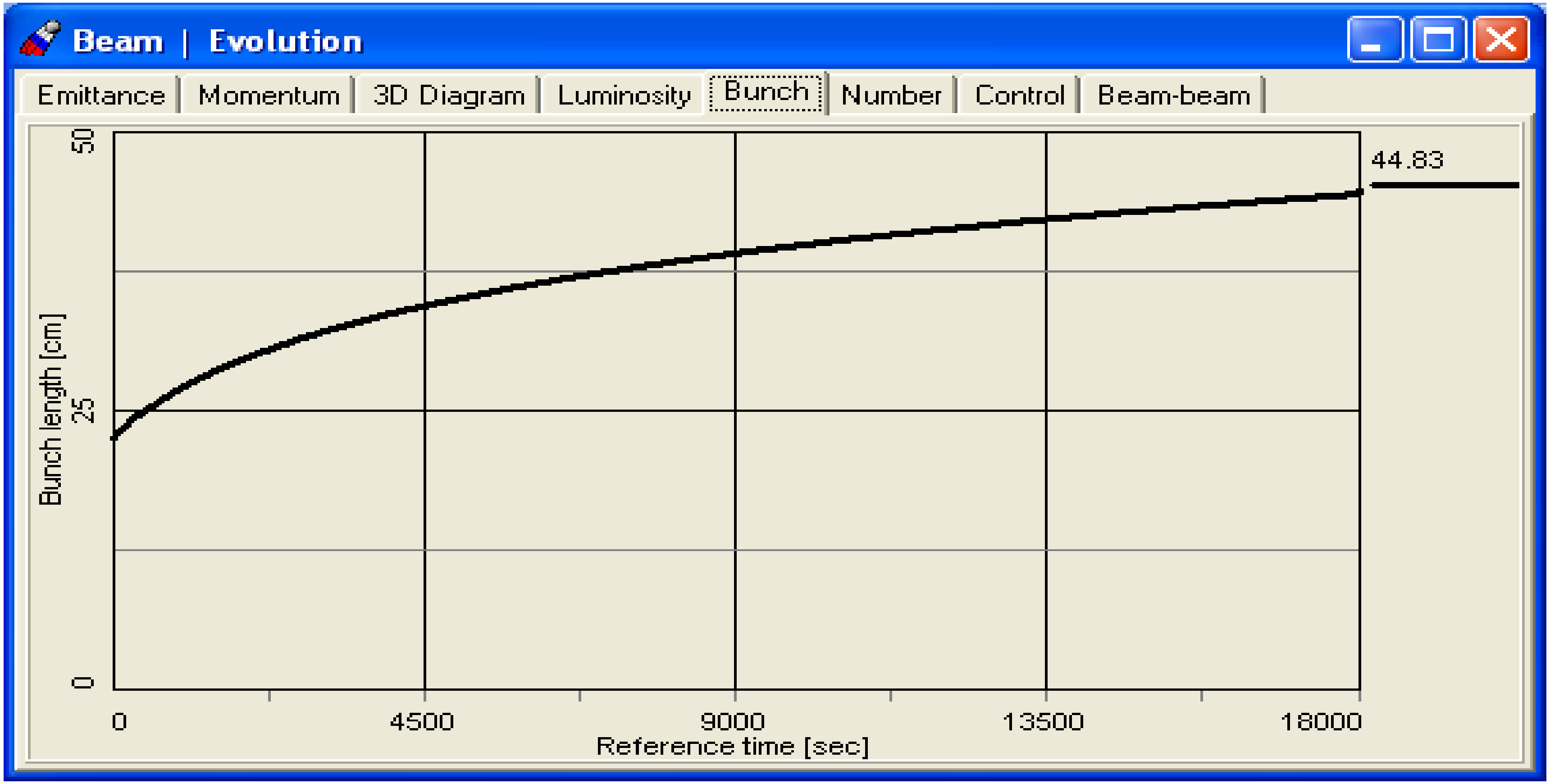
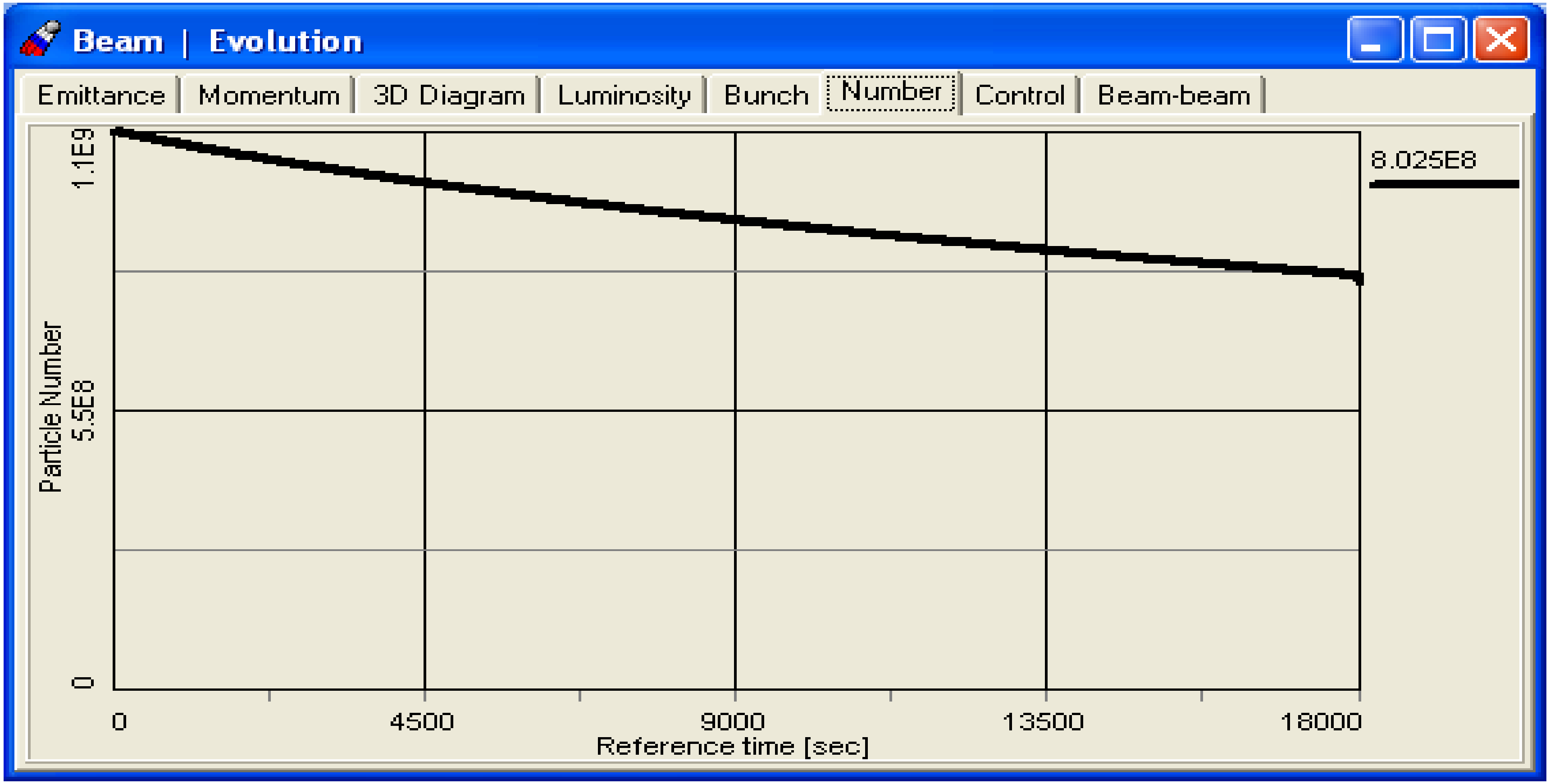
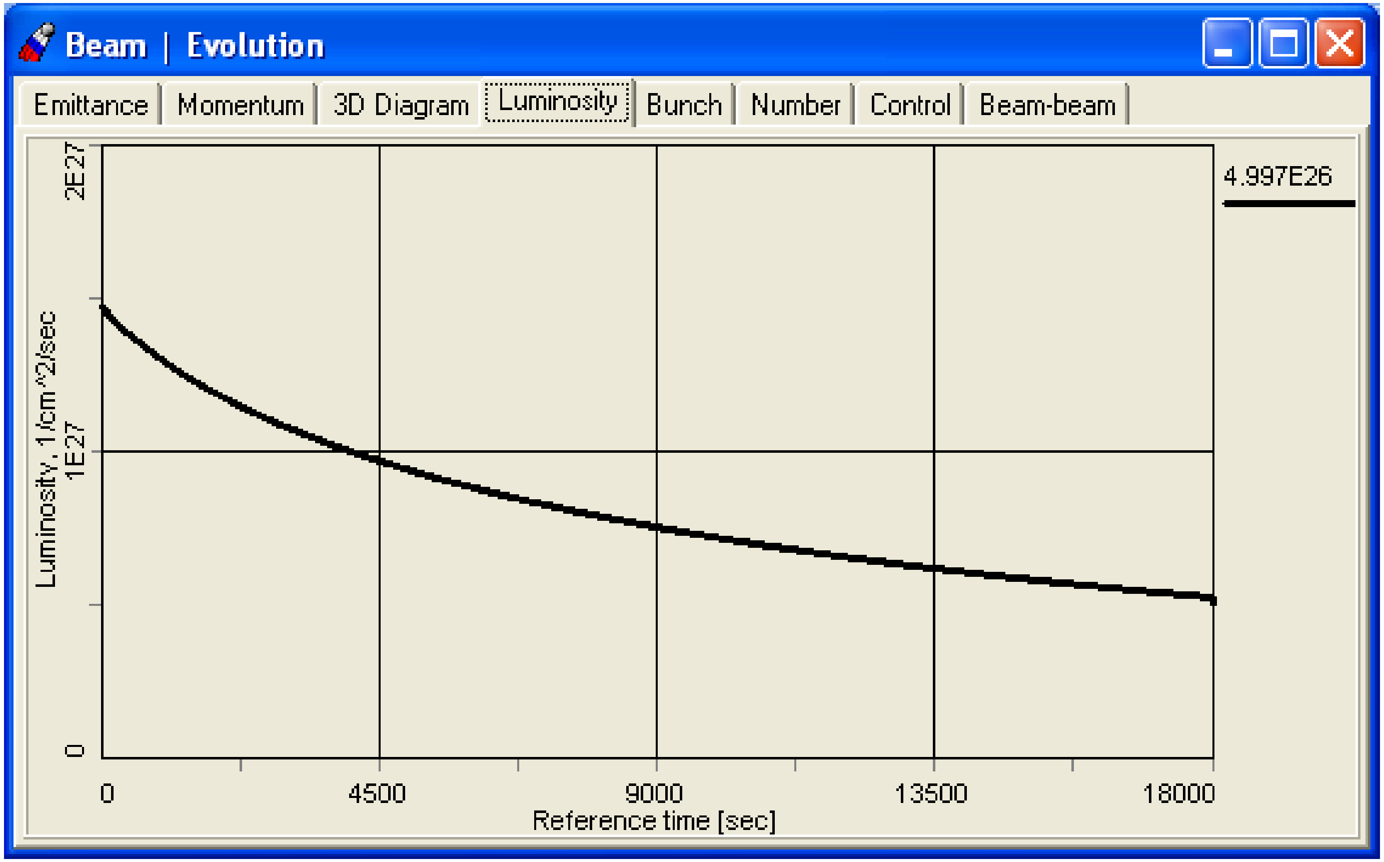
Martini (real lattice)



Martini (real lattice)



Martini (real lattice)



Summary for typical RHIC-4 store

J.Wei (FODO approximation):

Emittance increase: 15 π -> 32 π in 5 hours

Luminosity: $1.5*10^{27}$ -> $4.2*10^{26}$ factor of 3.6 decrease

Martini (RHIC-4 lattice):

Emittance: 15 π -> 23.4 π in 5 hours

Luminosity: $1.5*10^{27}$ -> $5*10^{26}$ factor of 3 decrease

Martini (RHIC-4 lattice):

Emittance: initial 12 π

Luminosity: $1.8*10^{27}$ -> $*10^{26}$ factor of 3.6 decrease